Welding Handbook

Sixth Edition

SECTION THREE

PART A

Welding, Cutting And Related Processes

Edited by Stanley T. Walter
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Welding Handbook

IN FIVE SECTIONS

1 Fundamentals of Welding
2 Welding Processes: Gas, Arc and Resistance
3 Special Welding Processes and Cutting
4 Metals and Their Weldability
5 Applications of Welding

Prepared under the direction of
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Preface

It is truly a reflection of the growth of our industry that this Sixth Edition of Volume 3, Welding, Cutting, and Related Processes, should be big. Since the last edition of this Volume was published five years ago, all the "old" welding processes have been refined, and "new" ones added to meet today's needs for more reliable and economical ways to join two or more parts together. The welding industry has never been so big as it is today.

Neither has Volume 3. The various Chapter Committees have completely reworked all 20 Chapters — and added significantly to the contents of each. This is a valuable contribution and we would not have it otherwise; however, the physical size of the book made it necessary for us to examine our own practices.

Because of the new information included in each of the 20 Chapters, it was necessary to editorially cull the material to bring it to producible size. Because the Chapter Committees had done such a fine job, the culling was limited to elimination of only illustrations and then only after much agonizing over each one. Despite all this, Volume 3 was still too large.

It was decided to split this Volume into Part A and Part B, each to include 10 Chapters. This is Part A, Chapters 40 to 50. Part B, Chapters 51 to 60, will follow, to complete the Sixth Edition of Volume 3, Welding, Cutting and Related Processes.

This course of action is the best way to bring AWS members and subscribers *all* the information, as *accurate* as we can make it, and as *promptly* as we can get it to you.

STANLEY T. WALTER, *Editor*

A special appreciation is in order for Stan Walter. Stan died just before this Section went to the printer. Many of us remember him as a willing worker on the various AWS Committees over the years, and we miss him as an AWS staff member and friend.

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CHAPTER 42

OXYGEN CUTTING

AUXILIARY OXYGEN CUTTING

PROCESSES

FUNDAMENTALS OF PROCESS

DEFINITION AND GENERAL DESCRIPTION

OXYGEN CUTTING is defined by AWS as a group of cutting processes wherein the severing or removing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In the case of oxidation-resistant metals the reaction is facilitated by the use of a chemical flux or metal powder. This flux may be in the form of a metallic or chemical powder, an abrasive agent or a mixture of both.

The introduction of the first oxygen cutting torch into this country shortly after 1900 caused a profound change in industrial practices having to do with the shaping of steel. Use of this process is now widespread; it can easily be used to shape many parts in a wide range of sizes and thicknesses which can only be worked with difficulty by other metal-shaping processes. Since the cut products are generally used in the "as-cut" condition, and the process is completely adaptable to welding and mechanical joining operations of all types, oxygen cutting has resulted in more economical construction and greatly increased production.

The oxygen cutting torch is a portable tool that can be taken to the work. It has been used to cut metal up to 94 in. in thickness. Because the cutting oxygen jet has a 360° cutting edge, it provides a rapid means of cutting not only straight lines, but can easily and economically cut many different shapes to required dimensions without expensive handling equipment.

PRINCIPLES OF OPERATION

Oxygen cutting is a means by which ferrous metal is severed by a rapid chemical reaction between the iron or its alloys and a confined high purity oxygen stream. A small area of the metal is preheated to the oxygen ignition temperature* of the ferrous metal and a stream of pure oxygen is impinged on the heated area. The oxygen rapidly oxidizes the metal in a narrow section, which becomes the kerf as the molten oxide and metal are removed by the kinetic energy of the oxygen stream.

The oxygen cutting process employs a torch and a tip or nozzle whose functions are: (1) to mix the fuel gas and preheat oxygen in the right proportion to produce the initial heating and continuous preheating effects, and (2) to supply a uniformly concentrated stream of high-purity oxygen to the reaction zone for the purpose of oxidizing and removing the molten materials. The torch unit is then conveyed across the material to be cut, at a speed sufficient to produce a continuous cutting action. This motion may be accomplished either manually or mechanically. The accuracy of the manual method depends largely on the skill of the operator; the machine method produces more accurate results with a superior finish.

CHEMISTRY OF OXYGEN CUTTING

The process of oxygen cutting is based on the capacity of high-purity oxygen to combine rapidly with iron that has been heated to the kindling temperature. Thus, when iron or steel is heated to its oxygen ignition temperature and brought into contact with high-purity oxygen, the iron is rapidly oxidized.

The balanced chemical equations** for this reaction are:

$$Fe + 0 \rightarrow Fe0 + \text{heat } (63{,}800 \text{ cal.}) \text{ first reaction}$$
$$3Fe + 20_2 \rightarrow Fe_30_4 + \text{heat } (267{,}800 \text{ cal.}) \text{ second reaction}$$
$$2Fe + 3/20_2 \rightarrow Fe_2O_3 + \text{heat } (196{,}800 \text{ cal.}) \text{ third reaction}$$

The third reaction occurs to some extent in heavier cutting operations, with the first and second predominating. Stoichiometrically, 4.6 cubic feet of oxygen will oxidize 1 pound of iron to Fe_30_4, but in practical cutting operations, the amount of oxygen used is appreciably less. This is because not all of the iron is completely oxidized to Fe_30_4. Some unoxidized or only partly oxidized metal is removed by the kinetic energy of the rapidly moving oxygen stream. Analysis of the slag has shown that, in some instances, over 30% is iron that has not been oxidized.

The heat generated by the combustion of iron to its oxides melts some of the iron adjacent to the reaction surface. Although this molten iron is swept away by the rapidly moving stream of oxygen and iron oxide, the concurrent oxidizing reaction heats the layer of iron at the active cutting front. Because this oxidation is not an instantaneous process, the heat developed by oxidation of the iron removed from an upper level of kerf is liberated at a lower level. In addition it is necessary to make up the thermal defficiency at the uppermost level where the oxidation reaction is just beginning by means of the preheating flames of the torch nozzle. These flames burn continuously while the torch is in motion.

The alloying elements that change iron to steel, when present in small amounts, are oxidized or dissolved in the slag without markedly interfering with the progress of the cut. However, when alloying elements are present in appreciable amounts, the effect on the cutting process must be considered. Steels containing oxidation-resistant elements can be oxygen cut, although when certain elements are present in large quantities (e.g., carbon, chromium, nickel, etc.) the technique required is different from that used with the plain carbon or with low-alloy steels.

DRAG

When the speed with which the nozzle travels across the work is such that the oxygen stream enters the top of the kerf and exits from the bottom of the kerf along the axis of the nozzle, the cut will have zero drag and is called a drop cut. If the speed of cutting is increased or if the quantity of cutting oxygen is below the recommended value, the portion of the oxygen jet farthest from the cutting nozzle will not be strong enough to carry on the controlled reaction, nor will it have sufficient energy to carry the products of the reaction straight through the work. The most distant part of the cutting stream will lag behind the portion nearest to the nozzle. The amount of this lag, measured along the line of cut, is referred to as the drag. A 10% drag means that the far side of the cut is behind the near side of the cut by an amount equal to 10% of the thickness of the material being cut. If for any reason the piece is not severed, the cut is referred to as a non-drop cut.

An increase in cutting speed usually results in an increase in the amount of drag, and may be accompanied by a decrease in quality. There is also a strong possibility of loss of cut at excessive speeds. Reverse drag may be obtained with too great a cutting oxygen flow or too slow a speed. However, under these conditions poor quality cuts usually result. Cutting stream lag resulting from incorrect torch alignment is not considered to be drag.

KERF

Kerf is defined as the space from which metal has been removed by a cutting process. It is the gap created by the removal of material by the cutting jet as it progresses across the material being cut. Kerf width is important for a number of reasons. Control or governing of kerf width plays an important part in the accuracy with which material can be cut to specified dimensions. Maintenance of a uniform kerf width from the torch side to the far side of the cut governs the squareness of the cut edge. Kerf width is a function of the size of nozzle, type of nozzle used, speed of cutting and flow rates of cutting oxygen and preheating gases. As the thickness of the material being cut increases, it is necessary to use greater oxygen flows and nozzles or tips with larger cutting oxygen passages in order to obtain a sufficient quantity of oxygen to cut through the material. The width of the kerf therefore increases as the thickness of the material being cut increases.

*The oxygen ignition temperature is the temperature at which the material will ignite when subjected to an atmosphere of high-purity oxygen.

**"Thermodynamic Properties of 65 Elements, Their Oxides, Halides, Carbides and Nitrides," Bureau of Mines, 1965, Bulletin 605.

Cutting at speeds below those recommended for best quality cuts usually results in irregularities in the kerf width as the oxygen stream melts, washes away and oxidizes additional quantities of the material on each side of the cut. Excessive preheat flow rate results in undesirable melting and widening of the kerf at the top. Kerf width is especially important when shape cutting. In laying out work or when designing templates, compensations must be made for kerf width. In general, on materials up to 2 in. thick, kerf width can be maintained within ± 1/64 inch.

PREHEATING TIME

Preheating time refers to the time required for the preheat flames to heat the base metal to ignition temperature; that is, to a temperature high enough that when the oxygen cutting jet is directed onto the heated areas, rapid oxidation will be initiated and the cutting operation will begin.

CLASSIFICATION OF OXYGEN CUTTING PROCESSES

MANUAL CUTTING

In manual cutting operations the cutting tip or nozzle is directed so that the preheat flames and the cutting jet impinge along the line of cut or in the area to be pierced or severed. Where a better quality cut is desired, or for reasons of convenience, the operator may employ a guide for the torch to maintain a given nozzle or tip-to-work distance, and to move the torch along a given path without lateral deviation. In Europe extensive use is made of one or more wheels to support the head of the torch, leaving the operator free to move the torch at fairly regular speed along the line of cut.

MACHINE CUTTING

In machine cuttting a machine functions as torch holder, locater, and speed-of-cut regulator in lieu of the operator used for manual cutting. The torch permits easy adjustment of the nozzle or tip with respect to the work—normally with a rack and pinion arrangement. Where the material to be cut is not flat, the torch may be equipped with a device that automatically maintains the correct nozzle or tip-to-work height. This device may employ a sensing and actuating device that is mechanical, electrical or pneumatic. A riding wheel type that is sometimes used is shown in Fig. 42.1. The machines, whether of the small tractor or tricycle type or of the more elaborate shape cutting variety, are designed so that, regardless of the path being traversed, the cutting speed remains constant at a preset value. The maintenance of a fixed nozzle height and speed, together with the proper nozzle size and recommended preheat gas and cutting oxygen flow, results in a high-quality cut surface with good dimensional qualities. A tractor-type machine, used for long straight cuts or circle cuts, may operate on tracks or on the work without tracks. Shape cutting is done with a more elaborate machine (usually track mounted) that follows some type of template, either mechanically or optically, or responds to signals from such devices as numerical tape control. Other machine cutting operations include the nicking or severing of billets, blooms and rounds (either hot or cold) stack cutting and the preparation of plate edges for welding.

SEVERING CUTS

Oxygen cutting is used to facilitate handling of material in preparation of scrap for remelting, for removal of risers on casting and in demolition work. In these cases, the object usually is to reduce the size of the pieces for easier handling or to remove unwanted material; the quality of the cut surface is unimportant. The speed of cutting is generally the most important consideration.

OPERATION

HIGH-SPEED CUTTING

High-quality as well as high-speed cuts are obtained when divergent bore nozzles are used. However, where speed is the prime consideration, and lower quality surfaces are acceptable, oversize cylindrical bore nozzles are generally used. Such high-speed cutting is frequently done with at least a 10% drag. High-speed cutting is generally limited to material 4 in. thick or less.

HIGH-QUALITY CUTTING

Essentials of high-quality cut surfaces are: squareness of top edge, smoothness of cut surface, squareness of the cut face with regard to top and bottom surfaces (on a horizontal member), absence of tenacious slag adhering to the surface farthest from the torch and production of a drop cut. These characteristics are desired on plates where edges are being prepared for welding, for "as-cut" fabrication or for good fitup, or for any application requiring good dimensional features. High-quality cuts can be obtained with either cylindrical or divergent bore nozzles. However, attention must be paid to the nozzle selection, cutting oxygen pressure and flow, cutting speed and the quantity and type of preheat flame. Light drag lines on cut surfaces are inherent and are not considered detrimental to quality.

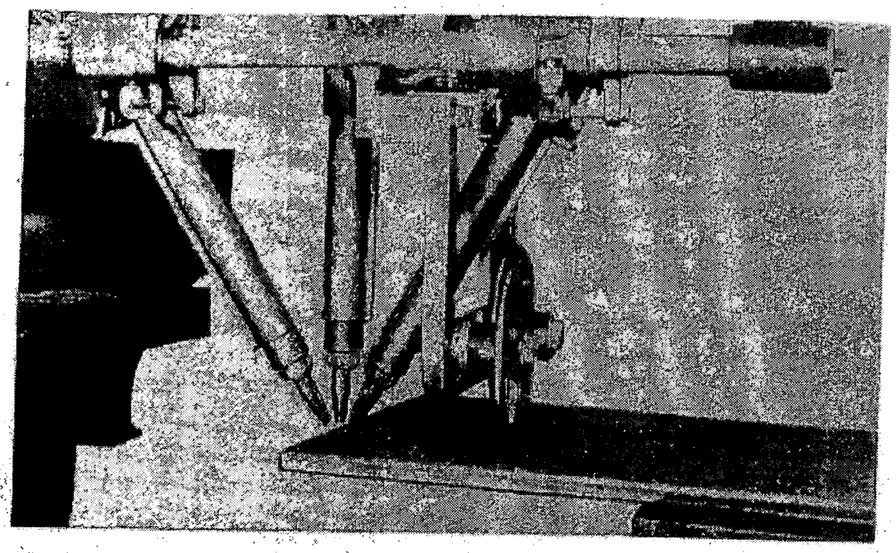

Fig. 42.1.—Riding wheel device used to maintain constant distance between work and cutting torch tip.

OXYGEN CUTTING

TECHNIQUE

Since the oxygen cutting process involves the continuous direction of a jet of high-purity oxygen onto an area of iron or steel that has been previously heated to the ignition temperature, the basic equipment employs preheating flames operating in conjunction with a high-purity oxygen stream. Both elements are supplied by a torch and nozzle combination that can be attached to fuel gas and oxygen sources. Torch and nozzles vary in design, depending on the specific type of cutting to be done.

Oxygen cutting torches are equipped with separable units called cutting tips or nozzles in which the oxygen cutting jet is surrounded, at a proper distance, by a number of preheating flames (Fig. 42.2). With this arrangement the torch may be moved in any direction without losing the effect of the preheating flames In addition, a uniform distribution of the preheating flames around the cutting oxygen stream helps to stabilize the stream and ensures a smoother cut surface, particularly during the cutting of heavy sections. Individual valves are generally so arranged that controls are available for the preheating fuel gas, the oxygen for preheating and the oxygen used for cutting.

In all oxygen cutting the preheating gases are first lighted, either with a spark lighter or pilot light, and the pressures adjusted so that the flames are uniform in length and shape and stable, with or without the cutting oxygen flowing. The preheating flames are then directed toward the spot where the cut is to be started and are allowed to impinge upon this area until the color of the spot indicates that the metal is at its kindling or ignition temperature. The cutting oxygen valve is then opened, and with the preheat flames still burning, the torch is advanced at a steady rate along the line of the cut. When the cutting is started within the workpiece (pierce start), the procedure must be modified to prevent the slag from blowing back on the nozzle. This can be achieved in handcutting by holding the nozzle at a slight angle or by moving the torch slowly in the direction of the cut until a hole has been pierced. In machine cutting the torch is moved in the cutting direction until the hole is pierced.

For machine cuts, auxiliary devices are available that permit rapid starts by employing high flow rates of preheating gases. The devices automatically or manually reduce the high starting flow rates to the desired low flow rate for cutting.

For oxygen cutting of square cuts, the nozzle is held perpendicular to the workpiece at a uniform distance above the surface. Usually this distance is such that the ends of the inner cones of the preheating flame just clear the surface of the metal. The placement of the preheat flames with respect to the kerf has an effect on quality, and must be properly oriented in the nozzle for each type of cutting. The torch is advanced steadily at the proper speed. If the speed of traverse is too great, the slag and oxide emerging from the bottom of the cut will trail behind or lag at too great an angle. When this happens, there is imminent danger of the stream failing to penetrate the steel completely. Regardless of whether the worker is using manual or machine cutting equipment, he must closely observe the slag emerging from the far side of the cut or the general nature of the course pursued by the oxygen and slag stream as it traverses through the steel, adjusting the speed of travel accordingly. If the movement is too fast, the cut may be lost completely and have to be restarted. If the movement is too slow, gouging and loss of quality may result.

FUEL GASES

A number of fuel gases may be used for the preheat flames in oxygen cutting. To determine which fuel gas to select for a particular application, an evaluation must be made of the various types of work to be done. Some of the factors to be considered when selecting the fuel gas are:

1. Time differentials for preheating in starting cuts on square edges, rounded corners, and when piercing holes for cut starts.
2. Effect on cutting speeds for straight line, shape and, particularly, bevel cutting.
3. Effect of items 1 and 2 on work output.
4. Cost of the fuel gas in cylinder, bulk and pipeline volumes.
5. Cost of the preheat oxygen required to burn the fuel gas efficiently.
6. Ability to use the fuel gas efficiently on operations such as scarfing, grooving, welding, heating and brazing, in addition to cutting, if required.
7. Ease of handling and availibility of fuel gas containers when mobility of operation is required.

For best results, it is essential that the torches and nozzles employed be designed for the particular fuel gas used.

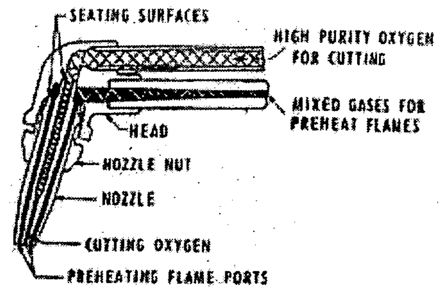

Fig. 42.2.—Closeup of torch head and nozzle showing preheating flame ports.

The functions of the preheat flames in the cutting operation are three-fold:

1. To raise the temperature of the steel to the ignition point in order to start and continue the cutting reaction.
2. To "condition" the cutting oxygen stream: i.e., the flames provide a protective shield between the cutting oxygen stream and the atmosphere. The flames also provide a transfer of heat energy to the oxygen stream that assists in propagating the cutting action, particularly in the lower depths of the cut.
3. To dislodge from the upper surface of the steel any rust, scale, paint or other foreign substance that would stop or retard the normal forward progress of the cutting action.

A preheat intensity that is sufficient to raise the steel to the ignition temperature rapidly will also be adequate for rapid and highly economical cutting. However, high quality, economical cutting can also be carried out at considerably lower preheat intensities than that normally required for rapid starting. In this latter case, auxiliary devices are used so that a high intensity preheat is employed for the starting operation and the flames are reduced to the lower preheat intensity for the cutting operation.

The fuel gases most commonly used for oxygen cutting are acetylene, natural gas and propane.

Acetylene

Acetylene gas is widely used as a fuel gas for oxygen cutting. Its chief advantages are: availability, high flame temperature and widespread familiarity of users with its flame characteristics.

The high flame temperature and heat transfer characteristics are particularly important for bevel cutting and for operations in which the starting time (such as for short cuts) is an appreciable fraction of the total time for cutting.

Natural Gas

The low cost and ready availability of natural gas in industrial areas make it a useful fuel for the preheating flames of cutting torches. Its characteristics as a fuel gas for oxygen cutting operations are much like those of propane. The same cutting tips are generally used for both propane and natural gas. Best operation requires 1¾ to 2 volumes of natural gas to 1 volume of preheat oxygen.

Propane

Propane is used regularly for oxygen cutting in a number of plants because of its availability, lower cost and ease of use. For proper combustion during cutting, propane requires 4 to 4½ times its volume of preheat oxygen. When oxygen costs are high this ratio offsets the economic benefits derived from the use of this low-cost fuel gas.

Other Fuel Gases

City gas (manufactured), coke oven and blast furnace gas (where it is available at low cost as a by-product of some other process) are sometimes used for fuel gas. The disadvantages of low heating value, low flame temperature and very low supply pressure usually result in changing to other fuel gases as they become available. Hydrogen, used in areas where it is similarly available as a low-cost by-product, was once employed almost exclusively for underwater cutting. It can safely be compressed to high pressures and regulated to overcome the pressure exerted by the water at salvage operations depths. Natural gas, which can be similarly compressed, is replacing hydrogen for underwater salvage operations, however.

A number of gases are specifically manufactured or compounded for use as oxygen cutting fuel gas. This group includes inoculated propane, stabilized methyl-acetylene and others. Claims for these gases include improved flame stability, higher flame temperature and lowered ignition temperature.

EFFECT OF OXYGEN PURITY

Oxygen used for cutting operations should have a purity of 99.5% or higher, since any decrease in purity from this level reduces the efficiency of the cutting operation. A 1% decrease in oxygen purity will result in a decrease in cutting speed of approximately 25% and an increase of about 25% in the cutting oxygen consumption. The quality of the cut will be impaired and the amount and tenacity of the adhering slag will increase. At oxygen purities below 95%, the familiar cutting action disappears and is replaced by a melt and wash action that is usually unacceptable for commercial operations. It is known that these changes are due to the chemical nature of oxygen cutting, although the precise ratios of cutting oxygen purity and cutting speeds, for example, have not been agreed upon.

EFFECTS OF PROCESSES

METALLURGICAL AND PHYSICAL

As explained previously, a large quantity of heat is liberated in the kerf when steel is cut with the oxygen jet. Much of this heat is transferred to the sides of the kerf, thereby heating the area adjacent to the kerf to a temperature above the critical temperature of the steel. Since the torch is constantly moving forward, the source of heat quickly moves on and the mass of cold metal near the kerf acts as a quenching medium, rapidly cooling the heated metal. The steel hardens to a degree that depends on the amount of carbon and alloying elements present, as well as the thickness of the material being cut.

A study of heat-affected zones from cutting operations shows that:

1. The depth of the heat-affected zone depends not only on the carbon and alloy content but also on the thickness of the base metal and the cutting speed employed.
2. Hardening of the heat-affected zones of constructional carbon steels of 0.25% maximum carbon is not critical in the thicknesses usually cut.
3. As might be expected, the higher carbon and alloy steels are hardened to such a degree that the thickness becomes critical.
4. The hardness effect progressively decreases as the distance from the kerf increases.

Typical examples of the heat effect of oxygen cutting are tabulated in Table 42.1. For most applications of oxygen cutting, the affected metal need not be removed. For unusual uses or with high alloy steels, the heat-affected zone may be removed by machining, grinding or other suitable means.

Bend and tensile tests made with specimens prepared from structural steel containing less than 0.25% carbon have shown that generally the detrimental effect of sawing or shearing are more severe than those of oxygen cutting.

From the results of tests and studies it is evident that the oxygen-cut surface of the lower carbon steels are at least equal in mechanical properties to the uncut metal. Most codes recognize this fact. The ASME Boiler and Pressure Vessel Code specifies that, "the edges must be uniform and smooth and must be freed of all loose scale and slag accumulations before welding." It further states that, "the discoloration which may remain on the flame-cut surface is not considered to be detrimental oxidation." The ASME Boiler and Pressure Vessel Code does not permit the welding of oxygen-cut surfaces in steel of over 0.35% carbon content.

Table 42.1—Approximate depth of heat-affected zone in oxygen cut steels*

Thickness, In.	Depths of Penetration, In.	
	Lower Carbon Steels	High Carbon and Alloy Steels
>1/2	>1/32	1/32
1/2	1/32	1/32 to 1/16
6	1/8	1/8 to 1/4

* The depth of penetration of the fully hardened zone is considerably thinner than the depth of the complete heat-affected zone.

CHEMICAL CHANGES

In addition to the phase changes resulting from oxygen cutting, there are chemical changes that extend to a slight depth. Samples taken from near the cut surface of carbon steels show a slightly higher carbon content than samples taken at a greater depth. The increase in carbon near the surface occurs whether the preheating flames are fed by a gas containing carbon, such as acetylene, or by a carbon-free gas such as hydrogen. Investigators have concluded that the carbon increase is from four potential sources:

1. Migration of carbon from the colder to the hotter metal.
2. Progressive precipitation of ferrite toward the high temperature at the face of the cut.
3. Absorption of carbon from the molten metal in the kerf.
4. Selective oxidation of the ferrite leaving the higher carbon cementite.

Nickel acts like carbon, concentrating at the surface of the cut; chromium and copper do the opposite; manganese and silicon are not appreciably affected. In general, these effects are minor.

EFFECTS OF ALLOYING ELEMENTS

Alloying elements have two possible effects on the oxygen cutting process: they may make the steel more difficult to cut and they may give rise to hardened or heat-checked cut surfaces. The first effect is roughly evaluated in Table 42.2.

HEAT TREATMENT

Plain carbon steels containing 0.25% carbon or less, in normal plate thicknesses, are not as a rule subject to cut surface hardening or cracking as a result of temperature or chemical changes due to oxygen cutting. An exception may be heavy sections or castings.

As the carbon content increases, or alloys are added, steels become more responsive to the heat treatment effect. It is therefore advisable to preheat the higher carbon and higher alloy steels before employing oxygen cutting. For steels with a carbon content greater than 0.25%, or any alloy steel that is

hardenable, preheating should always be employed. The need for preheating, greater for the heavier sections than for the lighter sections, becomes a requirement when heavy sections are to be cut to intricate shapes. Shapes with acute angles involving high stress concentrations should be preheated and stress relieved.

Preheating the work accomplishes several useful purposes:

1. It increases the efficiency of the cutting operation by permitting higher speeds thereby reducing the total amount of oxygen and fuel gas required to make the cut.
2. It reduces the temperature gradient set up by the cutting operation. This in turn reduces or gives more favorable distribution to the cooling stresses and prevents the formation of quenching or cooling cracks. Distortion is also reduced.
3. It reduces the hardness of the cut surface by reducing the rate of cooling.
4. It reduces the alloy migration toward the cut face by lowering the temperature differential between the cut face and the body of the metal.

The temperature used for preheating generally varies from 200 to about 1300°F (93 to 704°C), depending upon the size and type of steel to be cut. The majority of carbon and alloy steels requiring preheating may be cut with the steel preheated to the 400 to 600°F (204 to 316°C) temperature range. When the preheat temperature exceeds 1200 or 1300°F (204 to 316°C) the cutting operation approaches that of hot cutting. This is discussed in another section of this chapter. It should be noted here that the higher the temperature, the more rapid is the reaction of the oxygen with the iron; it is therefore possible to cut faster when the metal is preheated. But it is essential that the temperature be fairly uniform; if the outside of the metal being cut is at a lower temperature than the interior, the oxidation reaction will proceed more energetically in the interior than at the top and botom. The result is often the formation of large pockets in the interior that will either give rise to an unsatisfactory cut or to such slag pollution at lower levels that it will be impossible for the oxygen stream to penetrate the steel completely. Consequently, it is important that cutting be begun as soon as possible after the material is removed from the preheating furnace.

If preheating should prove impractical because of lack of facilities, the heat treatment effect and stresses incident to cutting may be reduced by other means. In the case of very light cutting this may be accomplished by passing the cutting torch, with the preheating flames lighted and the cutting oxygen turned off, slowly over the line of the cut until the metal in this region is raised to the approximate temperature desired. While one such pass may suffice, two or more passes generally yield better results. Another method which gives better results is to preheat the metal by means of an auxiliary multiflame heating tip mounted so as to precede the cutting tip.

To minimize the internal stresses set up in the steel by the oxygen cutting process, it is possible to utilize annealing, normalizing or stress-relieving processes subsequent to the cutting operation. By proper postheat treatment, all traces of metallurgical changes caused by oxygen cutting are eliminated. If a furnace is not available to carry out the heat treatment, or if it is impractical to use a furnace because of size, the cut surface may be reheated to the proper temperature by means of multiflame heating tips.

Table 42.2—Effect of alloying elements on resistance of steel to oxygen cutting

Element	Effect of Element on Oxygen Cutting
Carbon	Steels up to 0.25% carbon can be cut without difficulty. Higher carbon steels should be preheated to prevent hardening and cracking. Graphite and cementite (Fe_3C) are detrimental but cast irons containing 4% carbon can be cut by special techniques or processes described in later pages of this chapter.
Manganese	Steels of about 14% manganese and 1.5% carbon are cut with difficulty and for best results should be preheated.
Silicon	Silicon, in amounts usually present, has no effect. Transformer irons containing as much as 4% silicon are being cut. Silicon steel containing considerable amounts of carbon and manganese must be carefully preheated and post-annealed for best physical properties.
Chromium	Pure chromium reacts with oxygen only at very high temperatures. Steels up to 5% chromium are cut without much difficulty when the surface is clean. Higher chromium steels, such as 10% chromium steels, require special technique (see section on Oxidation Resistant Materials) and the cuts are rough when the usual oxyacetylene cutting process is used. In general, carburizing preheat flames are desirable when cutting this type of steel. The recently developed flux injection and iron powder cutting processes, described in a later section, enable cuts to be readily made in the usual straight chromium irons and steels as well as in stainless steel.
Nickel	Steels containing up to 3% nickel, if the carbon is not too high, may be cut by the normal oxygen cutting processes; up to about 7% nickel content, cuts are very satisfactory. Cuts of excellent quality may be made in the usual engineering alloys of the stainless steels (18-8 to about 35-15 as the upper limit) by the flux injection or iron powder cutting processes.
Molybdenum	This element affects cutting about the same as chromium. The pure metal is difficult to cut. Aircraft quality chrome-molybdenum steel offers no difficulties. High molybdenum-tungsten steels, however, may be cut only by means of special technique.
Tungsten	The pure metal may be cut if heated to a sufficient temperature. The usual alloys up to 12 or 14% may be cut very readily, but cutting is difficult with a higher percentage of tungsten. The limit seems to be about 20% tungsten.
Copper	In amounts up to about 2%, copper has no apparent effect.
Aluminum	Unless present in large amounts (on the order of 10%) the effect of aluminum is not appreciable.
Phosphorus	This element has no effect in amounts usually tolerated in steel.
Sulfur	Small amounts, such as are present in steels, have no effect. With higher percentages of sulfur, the rate of cutting is reduced and sulfur dioxide fumes are noticeable.
Vanadium	In the amounts usually found in steels, this alloy may improve rather than interfere with cutting.

OPERATING INFORMATION

Quality

In the production of components by oxygen cutting, the quality of the cut component is dependent on four factors: (1) metallurgical, (2) physical, (3) dimensional and (4) surface roughness. The first two categories have been covered previously and reliable reference values have been established and standardized for them. This is also somewhat true of the third category, but is not the case with the fourth—surface roughness. Parts identical in size, strength and analysis may differ considerably in the quailty of their surfaces. However, the quality of the surfaces could be adequate for the correct functioning of the parts in their intended service.

Acceptable quality is dependent on the job requirements. In cutting for scrapping operations, the only criterion is to part the material quickly with no consideration of surface roughness. When cutting high strength material to be used at high working stress, the surface roughness and dimensional tolerance are of utmost importance. In many of the latter applications, the cut surface must subsequently be ground and the corner rounded. Finally, the resulting cut must have a satisfactory slag condition. This again is dependent on the work. In scrap cutting it would not be considered, while in most production work there should be little or no firmly adhering slag.

Drag lines are inherent to oxygen cutting, being the line markings on the face of a cut. Fig. 42.3 shows typical drag conditions. The amount of drag is usually no criterion in considering surface roughness. However, too long a drag will result in a corner that is not completely severed at the completion of the cut. When all other conditions are correct, the drag lines would be the surface roughness. In oxygen cutting it is possible to approach 200 rms in surface roughness, with 800 to 1200 rms being average. Drag lines are also an indication of the conditions being used to make the cut.

Surface roughness of an oxygen cut surface of a particular thickness and type of steel is dependent on many variables, the most significant being:

1. Size and shape of the cutting oxygen orifice.
2. Cutting oxygen flow rate.
3. Cutting speed.
4. Purity of the oxygen.
5. Intensity (flow rate) of the preheat flames and the preheat oxy-fuel gas ratio.
6. Cleanliness and planeness of the exit end of the nozzle.
7. Condition of the steel surface.
8. Quality of steel, i.e., freedom from segregations, inclusions, etc.

Figures 42.4 and 42.5 show typical edge conditions resulting from variation in the cutting procedure.

For any given cut, the variables listed should be evaluated so that the quality of cut required may be obtained with the minimum aggregate cost in oxygen, fuel gas, labor and overhead.

Dimensional tolerance and surface roughness must be considered together when judging the quality of a cut; they are somewhat dependent on each other. Most specifications include dimensional tolerances. These include straightness of edge, squareness of edge and permissible variation in plate width, all of which are primarily a function of the cutting equipment and its mechanical operation. When the torch is held rigidly and advanced at a constant speed, as in machine-guided oxygen cutting, dimensional tolerances can be maintained within narrow limits. The degree of longitudinal precision of a machine guided cut depends primarily on such factors as the condition of the equipment, trueness of guide rails, clearances in the operating mechanism and the uniformity of speed control of the propelling unit. In addition to equipment, dimensional control is dependent on control of thermal expansion of the material being cut. Lack of adherence to dimensional tolerance may result from buckling of the material when sheet or thin plates are involved, warpage resulting from the

Fig. 42.3.—Typical drag conditions in 1 in. thick specimens (left), 0.11 in. drag with lower corner completely severed; (center) 0.20 in drag with corner completely severed; (right) 0.22 in. drag with lower corner not completly severed.

heat being applied to one edge or shifting of the material while it is being cut. With reasonable care and observation of the foregoing factors, cut surfaces in ordinary steel 6 in. in thickness can be held true as to cross-sectional squareness within $\pm 1/16$ inch. Cuts in thinner sections can be held within proportionally smaller limits.

Properly made machine-guided torch cuts are smooth with square edges and usually require no further finishing. Fig. 42.6 shows the condition of an oxygen-cut edge compared to rolled and sheared edges.

Precision cutting, either straight line or shape cutting, demands attention to all variables. The operations should therefore be planned carefully to minimize the effect of the variables. For instance, when trimming both sides of a plate, warpage will be lessened if two torches are mounted, one on each side, so that both cuts are made simultaneously and in the same direction. Distortion can often be controlled when making irregular cuts in plates by inserting wedges in the kerf following the cutting torch to limit the expansion of the metal. In cutting openings in the middle of a plate, it may be found advantageous from the standpoint of minimizing distortion to make a series of unconnected cuts leaving the cut out section attached to the plate in a number of places until the cut has been almost completed; the connecting parts can then be cut through last. Thin gage material is often stack cut, not only increasing production but also eliminating warping and buckling. Thin plate has also been cut submerged in water to remove the heat caused by cutting and thus minimize or prevent distortion.

PLATE EDGE PREPARATION

The beveling of plate edges before welding is a necessity in many applications, both to insure proper dimensions and fit, and to allow proper welding techniques to be employed. Beveling may employ a single torch or multiple torches operating simultaneously. Other forms of plate edge preparation such as "U" and "J" grooving are also used. These processes are covered later in this chapter.

Welding Handbook

Sixth Edition

SECTION THREE

PART A

Welding, Cutting
And
Related Processes

Edited by Stanley T. Walter
Published in 1970 by AMERICAN WELDING SOCIETY
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Welding Handbook

IN FIVE SECTIONS

1 Fundamentals of Welding
2 Welding Processes: Gas, Arc and Resistance
3 Special Welding Processes and Cutting
4 Metals and Their Weldability
5 Applications of Welding

Prepared under the direction of

THE WELDING HANDBOOK COMMITTEE

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Printed in the United States of America

Preface

It is truly a reflection of the growth of our industry that this Sixth Edition of Volume 3, Welding, Cutting, and Related Processes, should be big. Since the last edition of this Volume was published five years ago, all the "old" welding processes have been refined, and "new" ones added to meet today's needs for more reliable and economical ways to join two or more parts together. The welding industry has never been so big as it is today.

Neither has Volume 3. The various Chapter Committees have completely reworked all 20 Chapters — and added significantly to the contents of each. This is a valuable contribution and we would not have it otherwise; however, the physical size of the book made it necessary for us to examine our own practices.

Because of the new information included in each of the 20 Chapters, it was necessary to editorially cull the material to bring it to producible size. Because the Chapter Committees had done such a fine job, the culling was limited to elimination of only illustrations and then only after much agonizing over each one. Despite all this, Volume 3 was still too large.

It was decided to split this Volume into Part A and Part B, each to include 10 Chapters. This is Part A, Chapters 40 to 50. Part B, Chapters 51 to 60, will follow, to complete the Sixth Edition of Volume 3, Welding, Cutting and Related Processes.

This course of action is the best way to bring AWS members and subscribers *all* the information, as *accurate* as we can make it, and as *promptly* as we can get it to you.

STANLEY T. WALTER, *Editor*

A special appreciation is in order for Stan Walter. Stan died just before this Section went to the printer. Many of us remember him as a willing worker on the various AWS Committees over the years, and we miss him as an AWS staff member and friend.

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CHAPTER 42

OXYGEN CUTTING

AUXILIARY OXYGEN CUTTING

PROCESSES

FUNDAMENTALS OF PROCESS

DEFINITION AND GENERAL DESCRIPTION

OXYGEN CUTTING is defined by AWS as a group of cutting processes wherein the severing or removing of metals is effected by means of the chemical reaction of oxygen with the base metal at elevated temperatures. In the case of oxidation-resistant metals the reaction is facilitated by the use of a chemical flux or metal powder. This flux may be in the form of a metallic or chemical powder, an abrasive agent or a mixture of both.

The introduction of the first oxygen cutting torch into this country shortly after 1900 caused a profound change in industrial practices having to do with the shaping of steel. Use of this process is now widespread; it can easily be used to shape many parts in a wide range of sizes and thicknesses which can only be worked with difficulty by other metal-shaping processes. Since the cut products are generally used in the "as-cut" condition, and the process is completely adaptable to welding and mechanical joining operations of all types, oxygen cutting has resulted in more economical construction and greatly increased production.

The oxygen cutting torch is a portable tool that can be taken to the work. It has been used to cut metal up to 94 in. in thickness. Because the cutting oxygen jet has a 360° cutting edge, it provides a rapid means of cutting not only straight lines, but can easily and economically cut many different shapes to required dimensions without expensive handling equipment.

PRINCIPLES OF OPERATION

Oxygen cutting is a means by which ferrous metal is severed by a rapid chemical reaction between the iron or its alloys and a confined high purity oxygen stream. A small area of the metal is preheated to the oxygen ignition temperature* of the ferrous metal and a stream of pure oxygen is impinged on the heated area. The oxygen rapidly oxidizes the metal in a narrow section, which becomes the kerf as the molten oxide and metal are removed by the kinetic energy of the oxygen stream.

The oxygen cutting process employs a torch and a tip or nozzle whose functions are: (1) to mix the fuel gas and preheat oxygen in the right proportion to produce the initial heating and continuous preheating effects, and (2) to supply a uniformly concentrated stream of high-purity oxygen to the reaction zone for the purpose of oxidizing and removing the molten materials. The torch unit is then conveyed across the material to be cut, at a speed sufficient to produce a continuous cutting action. This motion may be accomplished either manually or mechanically. The accuracy of the manual method depends largely on the skill of the operator; the machine method produces more accurate results with a superior finish.

CHEMISTRY OF OXYGEN CUTTING

The process of oxygen cutting is based on the capacity of high-purity oxygen to combine rapidly with iron that has been heated to the kindling temperature. Thus, when iron or steel is heated to its oxygen ignition temperature and brought into contact with high-purity oxygen, the iron is rapidly oxidized.

The balanced chemical equations** for this reaction are:

$$Fe + 0 \rightarrow Fe0 + \text{heat (63,800 cal.) first reaction}$$
$$3Fe + 20_2 \rightarrow Fe_30_4 + \text{heat (267,800 cal.) second reaction}$$
$$2Fe + 3/20_2 \rightarrow Fe_2O_3 + \text{heat (196,800 cal.) third reaction}$$

The third reaction occurs to some extent in heavier cutting operations, with the first and second predominating. Stoichiometrically, 4.6 cubic feet of oxygen will oxidize 1 pound of iron to Fe_30_4, but in practical cutting operations, the amount of oxygen used is appreciably less. This is because not all of the iron is completely oxidized to Fe_30_4. Some unoxidized or only partly oxidized metal is removed by the kinetic energy of the rapidly moving oxygen stream. Analysis of the slag has shown that, in some instances, over 30% is iron that has not been oxidized.

The heat generated by the combustion of iron to its oxides melts some of the iron adjacent to the reaction surface. Although this molten iron is swept away by the rapidly moving stream of oxygen and iron oxide, the concurrent oxidizing reaction heats the layer of iron at the active cutting front. Because this oxidation is not an instantaneous process, the heat developed by oxidation of the iron removed from an upper level of kerf is liberated at a lower level. In addition it is necessary to make up the thermal defficiency at the uppermost level where the oxidation reaction is just beginning by means of the preheating flames of the torch nozzle. These flames burn continuously while the torch is in motion.

The alloying elements that change iron to steel, when present in small amounts, are oxidized or dissolved in the slag without markedly interfering with the progress of the cut. However, when alloying elements are present in appreciable amounts, the effect on the cutting process must be considered. Steels containing oxidation-resistant elements can be oxygen cut, although when certain elements are present in large quantities (e.g., carbon, chromium, nickel, etc.) the technique required is different from that used with the plain carbon or with low-alloy steels.

*The oxygen ignition temperature is the temperature at which the material will ignite when subjected to an atmosphere of high-purity oxygen.

**"Thermodynamic Properties of 65 Elements, Their Oxides, Halides, Carbides and Nitrides," Bureau of Mines, 1965, Bulletin 605.

DRAG

When the speed with which the nozzle travels across the work is such that the oxygen stream enters the top of the kerf and exits from the bottom of the kerf along the axis of the nozzle, the cut will have zero drag and is called a drop cut. If the speed of cutting is increased or if the quantity of cutting oxygen is below the recommended value, the portion of the oxygen jet farthest from the cutting nozzle will not be strong enough to carry on the controlled reaction, nor will it have sufficient energy to carry the products of the reaction straight through the work. The most distant part of the cutting stream will lag behind the portion nearest to the nozzle. The amount of this lag, measured along the line of cut, is referred to as the drag. A 10% drag means that the far side of the cut is behind the near side of the cut by an amount equal to 10% of the thickness of the material being cut. If for any reason the piece is not severed, the cut is referred to as a non-drop cut.

An increase in cutting speed usually results in an increase in the amount of drag, and may be accompanied by a decrease in quality. There is also a strong possibility of loss of cut at excessive speeds. Reverse drag may be obtained with too great a cutting oxygen flow or too slow a speed. However, under these conditions poor quality cuts usually result. Cutting stream lag resulting from incorrect torch alignment is not considered to be drag.

KERF

Kerf is defined as the space from which metal has been removed by a cutting process. It is the gap created by the removal of material by the cutting jet as it progresses across the material being cut. Kerf width is important for a number of reasons. Control or governing of kerf width plays an important part in the accuracy with which material can be cut to specified dimensions. Maintenance of a uniform kerf width from the torch side to the far side of the cut governs the squareness of the cut edge. Kerf width is a function of the size of nozzle, type of nozzle used, speed of cutting and flow rates of cutting oxygen and preheating gases. As the thickness of the material being cut increases, it is necessary to use greater oxygen flows and nozzles or tips with larger cutting oxygen passages in order to obtain a sufficient quantity of oxygen to cut through the material. The width of the kerf therefore increases as the thickness of the material being cut increases.

Cutting at speeds below those recommended for best quality cuts usually results in irregularities in the kerf width as the oxygen stream melts, washes away and oxidizes additional quantities of the material on each side of the cut. Excessive preheat flow rate results in undesirable melting and widening of the kerf at the top. Kerf width is especially important when shape cutting. In laying out work or when designing templates, compensations must be made for kerf width. In general, on materials up to 2 in. thick, kerf width can be maintained within ± 1/64 inch.

PREHEATING TIME

Preheating time refers to the time required for the preheat flames to heat the base metal to ignition temperature; that is, to a temperature high enough that when the oxygen cutting jet is directed onto the heated areas, rapid oxidation will be initiated and the cutting operation will begin.

CLASSIFICATION OF OXYGEN CUTTING PROCESSES

MANUAL CUTTING

In manual cutting operations the cutting tip or nozzle is directed so that the preheat flames and the cutting jet impinge along the line of cut or in the area to be pierced or severed. Where a better quality cut is desired, or for reasons of convenience, the operator may employ a guide for the torch to maintain a given nozzle or tip-to-work distance, and to move the torch along a given path without lateral deviation. In Europe extensive use is made of one or more wheels to support the head of the torch, leaving the operator free to move the torch at fairly regular speed along the line of cut.

MACHINE CUTTING

In machine cuttting a machine functions as torch holder, locater, and speed-of-cut regulator in lieu of the operator used for manual cutting. The torch permits easy adjustment of the nozzle or tip with respect to the work—normally with a rack and pinion arrangement. Where the material to be cut is not flat, the torch may be equipped with a device that automatically maintains the correct nozzle or tip-to-work height. This device may employ a sensing and actuating device that is mechanical, electrical or pneumatic. A riding wheel type that is sometimes used is shown in Fig. 42.1. The machines, whether of the small tractor or tricycle type or of the more elaborate shape cutting variety, are designed so that, regardless of the path being traversed, the cutting speed remains constant at a preset value. The maintenance of a fixed nozzle height and speed, together with the proper nozzle size and recommended preheat gas and cutting oxygen flow, results in a high-quality cut surface with good dimensional qualities. A tractor-type machine, used for long straight cuts or circle cuts, may operate on tracks or on the work without tracks. Shape cutting is done with a more elaborate machine (usually track mounted) that follows some type of template, either mechanically or optically, or responds to signals from such devices as numerical tape control. Other machine cutting operations include the nicking or severing of billets, blooms and rounds (either hot or cold) stack cutting and the preparation of plate edges for welding.

SEVERING CUTS

Oxygen cutting is used to facilitate handling of material in preparation of scrap for remelting, for removal of risers on casting and in demolition work. In these cases, the object usually is to reduce the size of the pieces for easier handling or to remove unwanted material; the quality of the cut surface is unimportant. The speed of cutting is generally the most important consideration.

OPERATION

HIGH-SPEED CUTTING

High-quality as well as high-speed cuts are obtained when divergent bore nozzles are used. However, where speed is the prime consideration, and lower quality surfaces are acceptable, oversize cylindrical bore nozzles are generally used. Such high-speed cutting is frequently done with at least a 10% drag. High-speed cutting is generally limited to material 4 in. thick or less.

HIGH-QUALITY CUTTING

Essentials of high-quality cut surfaces are: squareness of top edge, smoothness of cut surface, squareness of the cut face with regard to top and bottom surfaces (on a horizontal member), absence of tenacious slag adhering to the surface farthest from the torch and production of a drop cut. These characteristics are desired on plates where edges are being prepared for welding, for "as-cut" fabrication or for good fitup, or for any application requiring good dimensional features. High-quality cuts can be obtained with either cylindrical or divergent bore nozzles. However, attention must be paid to the nozzle selection, cutting oxygen pressure and flow, cutting speed and the quantity and type of preheat flame. Light drag lines on cut surfaces are inherent and are not considered detrimental to quality.

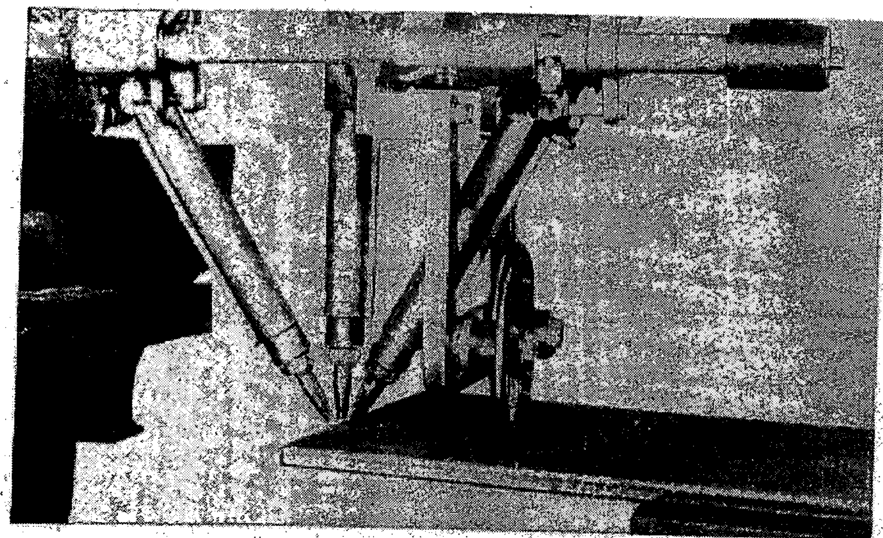


Fig. 42.1.—Riding wheel device used to maintain constant distance between work and cutting torch tip.

OXYGEN CUTTING

TECHNIQUE

Since the oxygen cutting process involves the continuous direction of a jet of high-purity oxygen onto an area of iron or steel that has been previously heated to the ignition temperature, the basic equipment employs preheating flames operating in conjunction with a high-purity oxygen stream. Both elements are supplied by a torch and nozzle combination that can be attached to fuel gas and oxygen sources. Torch and nozzles vary in design, depending on the specific type of cutting to be done.

Oxygen cutting torches are equipped with separable units called cutting tips or nozzles in which the oxygen cutting jet is surrounded, at a proper distance, by a number of preheating flames (Fig. 42.2). With this arrangement the torch may be moved in any direction without losing the effect of the preheating flames. In addition, a uniform distribution of the preheating flames around the cutting oxygen stream helps to stabilize the stream and ensures a smoother cut surface, particularly during the cutting of heavy sections. Individual valves are generally so arranged that controls are available for the preheating fuel gas, the oxygen for preheating and the oxygen used for cutting.

In all oxygen cutting the preheating gases are first lighted, either with a spark lighter or pilot light, and the pressures adjusted so that the flames are uniform in length and shape and stable, with or without the cutting oxygen flowing. The preheating flames are then directed toward the spot where the cut is to be started and are allowed to impinge upon this area until the color of the spot indicates that the metal is at its kindling or ignition temperature. The cutting oxygen valve is then opened, and with the preheat flames still burning, the torch is advanced at a steady rate along the line of the cut. When the cutting is started within the workpiece (pierce start), the procedure must be modified to prevent the slag from blowing back on the nozzle. This can be achieved in handcutting by holding the nozzle at a slight angle or by moving the torch slowly in the direction of the cut until a hole has been pierced. In machine cutting the torch is moved in the cutting direction until the hole is pierced.

For machine cuts, auxiliary devices are available that permit rapid starts by employing high flow rates of preheating gases. The devices automatically or manually reduce the high starting flow rates to the desired low flow rate for cutting.

For oxygen cutting of square cuts, the nozzle is held perpendicular to the workpiece at a uniform distance above the surface. Usually this distance is such that the ends of the inner cones of the preheating flame just clear the surface of the metal. The placement of the preheat flames with respect to the kerf has an effect on quality, and must be properly oriented in the nozzle for each type of cutting. The torch is advanced steadily at the proper speed. If the speed of traverse is too great, the slag and oxide emerging from the bottom of the cut will trail behind or lag at too great an angle. When this happens, there is imminent danger of the stream failing to penetrate the steel completely. Regardless of whether the worker is using manual or machine cutting equipment, he must closely observe the slag emerging from the far side of the cut or the general nature of the course pursued by the oxygen and slag stream as it traverses through the steel, adjusting the speed of travel accordingly. If the movement is too fast, the cut may be lost completely and have to be restarted. If the movement is too slow, gouging and loss of quality may result.

FUEL GASES

A number of fuel gases may be used for the preheat flames in oxygen cutting. To determine which fuel gas to select for a particular application, an evaluation must be made of the various types of work to be done. Some of the factors to be considered when selecting the fuel gas are:

1. Time differentials for preheating in starting cuts on square edges, rounded corners, and when piercing holes for cut starts.
2. Effect on cutting speeds for straight line, shape and, particularly, bevel cutting.
3. Effect of items 1 and 2 on work output.
4. Cost of the fuel gas in cylinder, bulk and pipeline volumes.
5. Cost of the preheat oxygen required to burn the fuel gas efficiently.
6. Ability to use the fuel gas efficiently on operations such as scarfing, grooving, welding, heating and brazing, in addition to cutting, if required.
7. Ease of handling and availibility of fuel gas containers when mobility of operation is required.

For best results, it is essential that the torches and nozzles employed be designed for the particular fuel gas used.

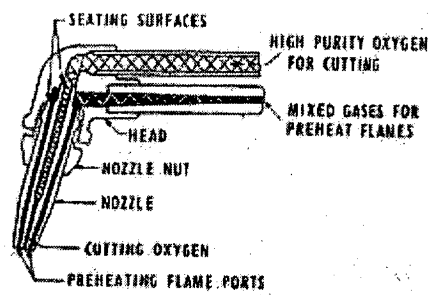


Fig. 42.2.—Closeup of torch head and nozzle showing preheating flame ports.

The functions of the preheat flames in the cutting operation are three-fold:

1. To raise the temperature of the steel to the ignition point in order to start and continue the cutting reaction.
2. To "condition" the cutting oxygen stream: i.e., the flames provide a protective shield between the cutting oxygen stream and the atmosphere. The flames also provide a transfer of heat energy to the oxygen stream that assists in propagating the cutting action, particularly in the lower depths of the cut.
3. To dislodge from the upper surface of the steel any rust, scale, paint or other foreign substance that would stop or retard the normal forward progress of the cutting action.

A preheat intensity that is sufficient to raise the steel to the ignition temperature rapidly will also be adequate for rapid and highly economical cutting. However, high quality, economical cutting can also be carried out at considerably lower preheat intensities than that normally required for rapid starting. In this latter case, auxiliary devices are used so that a high intensity preheat is employed for the starting operation and the flames are reduced to the lower preheat intensity for the cutting operation.

The fuel gases most commonly used for oxygen cutting are acetylene, natural gas and propane.

Acetylene

Acetylene gas is widely used as a fuel gas for oxygen cutting. Its chief advantages are: availability, high flame temperature and widespread familiarity of users with its flame characteristics.

The high flame temperature and heat transfer characteristics are particularly important for bevel cutting and for operations in which the starting time (such as for short cuts) is an appreciable fraction of the total time for cutting.

Natural Gas

The low cost and ready availability of natural gas in industrial areas make it a useful fuel for the preheating flames of cutting torches. Its characteristics as a fuel gas for oxygen cutting operations are much like those of propane. The same cutting tips are generally used for both propane and natural gas. Best operation requires 1¾ to 2 volumes of natural gas to 1 volume of preheat oxygen.

Propane

Propane is used regularly for oxygen cutting in a number of plants because of its availability, lower cost and ease of use. For proper combustion during cutting, propane requires 4 to 4½ times its volume of preheat oxygen. When oxygen costs are high this ratio offsets the economic benefits derived from the use of this low-cost fuel gas.

Other Fuel Gases

City gas (manufactured), coke oven and blast furnace gas (where it is available at low cost as a by-product of some other process) are sometimes used for fuel gas. The disadvantages of low heating value, low flame temperature and very low supply pressure usually result in changing to other fuel gases as they become available. Hydrogen, used in areas where it is similarly available as a low-cost by-product, was once employed almost exclusively for underwater cutting. It can safely be compressed to high pressures and regulated to overcome the pressure exerted by the water at salvage operations depths. Natural gas, which can be similarly compressed, is replacing hydrogen for underwater salvage operations, however.

A number of gases are specifically manufactured or compounded for use as oxygen cutting fuel gas. This group includes inoculated propane, stabilized methyl-acetylene and others. Claims for these gases include improved flame stability, higher flame temperature and lowered ignition temperature.

EFFECT OF OXYGEN PURITY

Oxygen used for cutting operations should have a purity of 99.5% or higher, since any decrease in purity from this level reduces the efficiency of the cutting operation. A 1% decrease in oxygen purity will result in a decrease in cutting speed of approximately 25% and an increase of about 25% in the cutting oxygen consumption. The quality of the cut will be impaired and the amount and tenacity of the adhering slag will increase. At oxygen purities below 95%, the familiar cutting action disappears and is replaced by a melt and wash action that is usually unacceptable for commercial operations. It is known that these changes are due to the chemical nature of oxygen cutting, although the precise ratios of cutting oxygen purity and cutting speeds, for example, have not been agreed upon.

EFFECTS OF PROCESSES

METALLURGICAL AND PHYSICAL

As explained previously, a large quantity of heat is liberated in the kerf when steel is cut with the oxygen jet. Much of this heat is transferred to the sides of the kerf, thereby heating the area adjacent to the kerf to a temperature above the critical temperature of the steel. Since the torch is constantly moving forward, the source of heat quickly moves on and the mass of cold metal near the kerf acts as a quenching medium, rapidly cooling the heated metal. The steel hardens to a degree that depends on the amount of carbon and alloying elements present, as well as the thickness of the material being cut.

A study of heat-affected zones from cutting operations shows that:

1. The depth of the heat-affected zone depends not only on the carbon and alloy content but also on the thickness of the base metal and the cutting speed employed.
2. Hardening of the heat-affected zones of constructional carbon steels of 0.25% maximum carbon is not critical in the thicknesses usually cut.
3. As might be expected, the higher carbon and alloy steels are hardened to such a degree that the thickness becomes critical.
4. The hardness effect progressively decreases as the distance from the kerf increases.

Typical examples of the heat effect of oxygen cutting are tabulated in Table 42.1. For most applications of oxygen cutting, the affected metal need not be removed. For unusual uses or with high alloy steels, the heat-affected zone may be removed by machining, grinding or other suitable means.

Bend and tensile tests made with specimens prepared from structural steel containing less than 0.25% carbon have shown that generally the detrimental effect of sawing or shearing are more severe than those of oxygen cutting.

From the results of tests and studies it is evident that the oxygen-cut surface of the lower carbon steels are at least equal in mechanical properties to the uncut metal. Most codes recognize this fact. The ASME Boiler and Pressure Vessel Code specifies that, "the edges must be uniform and smooth and must be freed of all loose scale and slag accumulations before welding." It further states that, "the discoloration which may remain on the flame-cut surface is not considered to be detrimental oxidation." The ASME Boiler and Pressure Vessel Code does not permit the welding of oxygen-cut surfaces in steel of over 0.35% carbon content.

Table 42.1—Approximate depth of heat-affected zone in oxygen cut steels*

Thickness, In.	Depths of Penetration, In.	
	Lower Carbon Steels	High Carbon and Alloy Steels
>1/2	>1/32	1/32
1/2	1/16	1/32 to 1/16
6	1/8	1/8 to 1/4

* The depth of penetration of the fully hardened zone is considerably thinner than the depth of the complete heat-affected zone.

CHEMICAL CHANGES

In addition to the phase changes resulting from oxygen cutting, there are chemical changes that extend to a slight depth. Samples taken from near the cut surface of carbon steels show a slightly higher carbon content than samples taken at a greater depth. The increase in carbon near the surface occurs whether the preheating flames are fed by a gas containing carbon, such as acetylene, or by a carbon-free gas such as hydrogen. Investigators have concluded that the carbon increase is from four potential sources:

1. Migration of carbon from the colder to the hotter metal.
2. Progressive precipitation of ferrite toward the high temperature at the face of the cut.
3. Absorption of carbon from the molten metal in the kerf.
4. Selective oxidation of the ferrite leaving the higher carbon cementite.

Nickel acts like carbon, concentrating at the surface of the cut; chromium and copper do the opposite; manganese and silicon are not appreciably affected. In general, these effects are minor.

EFFECTS OF ALLOYING ELEMENTS

Alloying elements have two possible effects on the oxygen cutting process: they may make the steel more difficult to cut and they may give rise to hardened or heat-checked cut surfaces. The first effect is roughly evaluated in Table 42.2.

HEAT TREATMENT

Plain carbon steels containing 0.25% carbon or less, in normal plate thicknesses, are not as a rule subject to cut surface hardening or cracking as a result of temperature or chemical changes due to oxygen cutting. An exception may be heavy sections or castings.

As the carbon content increases, or alloys are added, steels become more responsive to the heat treatment effect. It is therefore advisable to preheat the higher carbon and higher alloy steels before employing oxygen cutting. For steels with a carbon content greater than 0.25%, or any alloy steel that is

hardenable, preheating should always be employed. The need for preheating, greater for the heavier sections than for the lighter sections, becomes a requirement when heavy sections are to be cut to intricate shapes. Shapes with acute angles involving high stress concentrations should be preheated and stress relieved.

Preheating the work accomplishes several useful purposes:

1. It increases the efficiency of the cutting operation by permitting higher speeds thereby reducing the total amount of oxygen and fuel gas required to make the cut.
2. It reduces the temperature gradient set up by the cutting operation. This in turn reduces or gives more favorable distribution to the cooling stresses and prevents the formation of quenching or cooling cracks. Distortion is also reduced.
3. It reduces the hardness of the cut surface by reducing the rate of cooling.
4. It reduces the alloy migration toward the cut face by lowering the temperature differential between the cut face and the body of the metal.

The temperature used for preheating generally varies from 200 to about 1300°F (93 to 704°C), depending upon the size and type of steel to be cut. The majority of carbon and alloy steels requiring preheating may be cut with the steel preheated to the 400 to 600°F (204 to 316°C) temperature range. When the preheat temperature exceeds 1200 or 1300°F (204 to 316°C) the cutting operation approaches that of hot cutting. This is discussed in another section of this chapter. It should be noted here that the higher the temperature, the more rapid is the reaction of the oxygen with the iron; it is therefore possible to cut faster when the metal is preheated. But it is essential that the temperature be fairly uniform; if the outside of the metal being cut is at a lower temperature than the interior, the oxidation reaction will proceed more energetically in the interior than at the top and botom. The result is often the formation of large pockets in the interior that will either give rise to an unsatisfactory cut or to such slag pollution at lower levels that it will be impossible for the oxygen stream to penetrate the steel completely. Consequently, it is important that cutting be begun as soon as possible after the material is removed from the preheating furnace.

If preheating should prove impractical because of lack of facilities, the heat treatment effect and stresses incident to cutting may be reduced by other means. In the case of very light cutting this may be accomplished by passing the cutting torch, with the preheating flames lighted and the cutting oxygen turned off, slowly over the line of the cut until the metal in this region is raised to the approximate temperature desired. While one such pass may suffice, two or more passes generally yield better results. Another method which gives better results is to preheat the metal by means of an auxiliary multiflame heating tip mounted so as to precede the cutting tip.

To minimize the internal stresses set up in the steel by the oxygen cutting process, it is possible to utilize annealing, normalizing or stress-relieving processes subsequent to the cutting operation. By proper postheat treatment, all traces of metallurgical changes caused by oxygen cutting are eliminated. If a furnace is not available to carry out the heat treatment, or if it is impractical to use a furnace because of size, the cut surface may be reheated to the proper temperature by means of multiflame heating tips.

Table 42.2—Effect of alloying elements on resistance of steel to oxygen cutting

Element	Effect of Element on Oxygen Cutting
Carbon	Steels up to 0.25% carbon can be cut without difficulty. Higher carbon steels should be preheated to prevent hardening and cracking. Graphite and cementite (Fe_3C) are detrimental but cast irons containing 4% carbon can be cut by special techniques or processes described in later pages of this chapter.
Manganese	Steels of about 14% manganese and 1.5% carbon are cut with difficulty and for best results should be preheated.
Silicon	Silicon, in amounts usually present, has no effect. Transformer irons containing as much as 4% silicon are being cut. Silicon steel containing considerable amounts of carbon and manganese must be carefully preheated and post-annealed for best physical properties.
Chromium	Pure chromium reacts with oxygen only at very high temperatures. Steels up to 5% chromium are cut without much difficulty when the surface is clean. Higher chromium steels, such as 10% chromium steels, require special technique (see section on Oxidation Resistant Materials) and the cuts are rough when the usual oxyacetylene cutting process is used. In general, carburizing preheat flames are desirable when cutting this type of steel. The recently developed flux injection and iron powder cutting processes, described in a later section, enable cuts to be readily made in the usual straight chromium irons and steels as well as in stainless steel.
Nickel	Steels containing up to 3% nickel, if the carbon is not too high, may be cut by the normal oxygen cutting processes; up to about 7% nickel content, cuts are very satisfactory. Cuts of excellent quality may be made in the usual engineering alloys of the stainless steels (18-8 to about 35-15 as the upper limit) by the flux injection or iron powder cutting processes.
Molybdenum	This element affects cutting about the same as chromium. The pure metal is difficult to cut. Aircraft quality chrome-molybdenum steel offers no difficulties. High molybdenum-tungsten steels, however, may be cut only by means of special technique.
Tungsten	The pure metal may be cut if heated to a sufficient temperature. The usual alloys up to 12 or 14% may be cut very readily, but cutting is difficult with a higher percentage of tungsten. The limit seems to be about 20% tungsten.
Copper	In amounts up to about 2%, copper has no apparent effect.
Aluminum	Unless present in large amounts (on the order of 10%) the effect of aluminum is not appreciable.
Phosphorus	This element has no effect in amounts usually tolerated in steel.
Sulfur	Small amounts, such as are present in steels, have no effect. With higher percentages of sulfur, the rate of cutting is reduced and sulfur dioxide fumes are noticeable.
Vanadium	In the amounts usually found in steels, this alloy may improve rather than interfere with cutting.

OPERATING INFORMATION

Quality

In the production of components by oxygen cutting, the quality of the cut component is dependent on four factors: (1) metallurgical, (2) physical, (3) dimensional and (4) surface roughness. The first two categories have been covered previously and reliable reference values have been established and standardized for them. This is also somewhat true of the third category, but is not the case with the fourth—surface roughness. Parts identical in size, strength and analysis may differ considerably in the quality of their surfaces. However, the quality of the surfaces could be adequate for the correct functioning of the parts in their intended service.

Acceptable quality is dependent on the job requirements. In cutting for scrapping operations, the only criterion is to part the material quickly with no consideration of surface roughness. When cutting high strength material to be used at high working stress, the surface roughness and dimensional tolerance are of utmost importance. In many of the latter applications, the cut surface must subsequently be ground and the corner rounded. Finally, the resulting cut must have a satisfactory slag condition. This again is dependent on the work. In scrap cutting it would not be considered, while in most production work there should be little or no firmly adhering slag.

Drag lines are inherent to oxygen cutting, being the line markings on the face of a cut. Fig. 42.3 shows typical drag conditions. The amount of drag is usually no criterion in considering surface roughness. However, too long a drag will result in a corner that is not completely severed at the completion of the cut. When all other conditions are correct, the drag lines would be the surface roughness. In oxygen cutting it is possible to approach 200 rms in surface roughness, with 800 to 1200 rms being average. Drag lines are also an indication of the conditions being used to make the cut.

Surface roughness of an oxygen cut surface of a particular thickness and type of steel is dependent on many variables, the most significant being:

1. Size and shape of the cutting oxygen orifice.
2. Cutting oxygen flow rate.
3. Cutting speed.
4. Purity of the oxygen.
5. Intensity (flow rate) of the preheat flames and the preheat oxy-fuel gas ratio.
6. Cleanliness and planeness of the exit end of the nozzle.
7. Condition of the steel surface.
8. Quality of steel, i.e., freedom from segregations, inclusions, etc.

Figures 42.4 and 42.5 show typical edge conditions resulting from variation in the cutting procedure.

For any given cut, the variables listed should be evaluated so that the quality of cut required may be obtained with the minimum aggregate cost in oxygen, fuel gas, labor and overhead.

Dimensional tolerance and surface roughness must be considered together when judging the quality of a cut; they are somewhat dependent on each other. Most specifications include dimensional tolerances. These include straightness of edge, squareness of edge and permissible variation in plate width, all of which are primarily a function of the cutting equipment and its mechanical operation. When the torch is held rigidly and advanced at a constant speed, as in machine-guided oxygen cutting, dimensional tolerances can be maintained within narrow limits. The degree of longitudinal precision of a machine guided cut depends primarily on such factors as the condition of the equipment, trueness of guide rails, clearances in the operating mechanism and the uniformity of speed control of the propelling unit. In addition to equipment, dimensional control is dependent on control of thermal expansion of the material being cut. Lack of adherence to dimensional tolerance may result from buckling of the material when sheet or thin plates are involved, warpage resulting from the

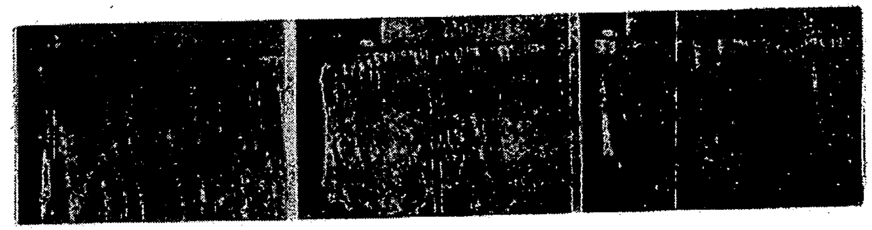


Fig. 42.3.—Typical drag conditions in 1 in. thick specimens (left), 0.11 in. drag with lower corner completely severed; (center) 0.20 in drag with corner completely severed; (right) 0.22 in. drag with lower corner not complitely severed.

heat being applied to one edge or shifting of the material while it is being cut. With reasonable care and observation of the foregoing factors, cut surfaces in ordinary steel 6 in. in thickness can be held true as to cross-sectional squareness within $\pm 1/16$ inch. Cuts in thinner sections can be held within proportionally smaller limits.

Properly made machine-guided torch cuts are smooth with square edges and usually require no further finishing. Fig. 42.6 shows the condition of an oxygen-cut edge compared to rolled and sheared edges.

Precision cutting, either straight line or shape cutting, demands attention to all variables. The operations should therefore be planned carefully to minimize the effect of the variables. For instance, when trimming both sides of a plate, warpage will be lessened if two torches are mounted, one on each side, so that both cuts are made simultaneously and in the same direction. Distortion can often be controlled when making irregular cuts in plates by inserting wedges in the kerf following the cutting torch to limit the expansion of the metal. In cutting openings in the middle of a plate, it may be found advantageous from the standpoint of minimizing distortion to make a series of unconnected cuts leaving the cut out section attached to the plate in a number of places until the cut has been almost completed; the connecting parts can then be cut through last. Thin gage material is often stack cut, not only increasing production but also eliminating warping and buckling. Thin plate has also been cut submerged in water to remove the heat caused by cutting and thus minimize or prevent distortion.

PLATE EDGE PREPARATION

The beveling of plate edges before welding is a necessity in many applications, both to insure proper dimensions and fit, and to allow proper welding techniques to be employed. Beveling may employ a single torch or multiple torches operating simultaneously. Other forms of plate edge preparation such as "U" and "J" grooving are also used. These processes are covered later in this chapter.

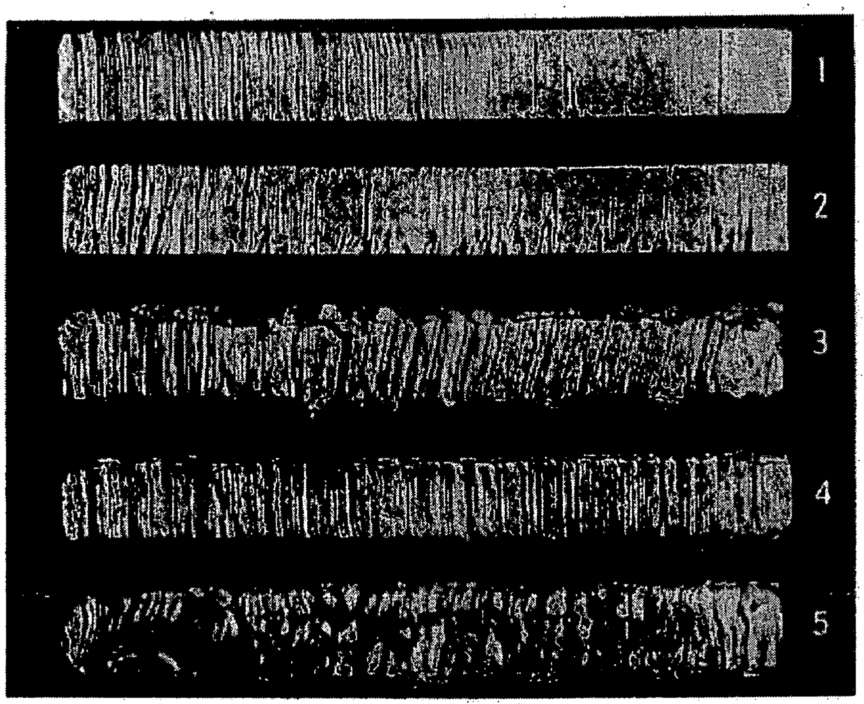


Fig. 42.4.—Typical edge conditions resulting from oxygen cutting operations. (1) Good cut in 1 in. plate. The edge is square and the draglines are essentially vertical and not too pronounced. (2) Preheat flames were too small for this cut with the result that the cutting speed was too slow, causing bad gouging at the bottom. (3) Preheating flames were too long, with the result that the top surface has melted over, the cut edge is irregular, and there is an excessive amount of adhering slag. (4) Oxygen pressure was too low, with the result that the top edge has melted over because of the slow cutting speed. (5) Oxygen pressure was too high and the nozzle size too small, with the result that control of the cut has been lost.

In single torch beveling, the amount and type of preheat is a dominant factor. At angles less than 15° from the vertical, the loss of preheat efficiency is small; however, as the angle increases above 15° the loss in heat transfer from the preheat flames to the plate becomes appreciable and considerably greater preheat input is required, particularly for thicknesses up to one inch.

Best results are obtained by adjusting the nozzle very close to the work and employing the following oxy-fuel gas ratios:

1.5 oxygen to 1 acetylene
4.7 oxygen to 1 propane
2 oxygen to 1 natural gas

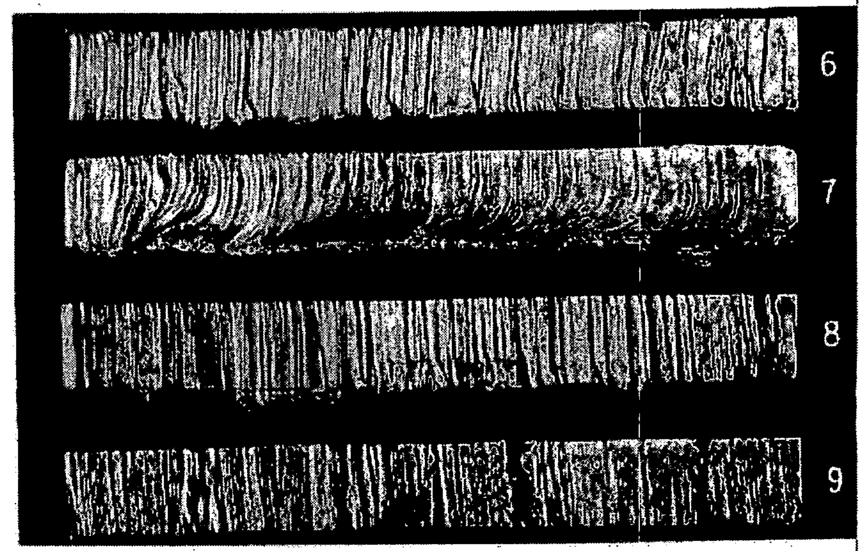


Fig. 42.5.—Typical edge conditions resulting from oxygen cutting operations. (6) Cutting speed was too slow, with the result that the irregularities of the draglines ar emphasized. (7) Cutting speed was too fast, with the result that there is a pronounce break in the dragline and the cut edge is irregular. (8) Torch travel was unstead with the result that the cut edge is wavy and irregular. (9) Cut was lost and n carefully restarted, with the result that bad gouges were caused at the restarting poin

An auxiliary torch (with only preheat flames burning) mounted perpendicu lar to the work or an auxiliary adapter (used in a single torch), which divide the preheat and applies a portion of it at right angles to the work, may be use to obtain faster beveling speeds. Either method actually consumes less tota preheat gases than a single angled nozzle.

Highest quality of cut face is not always obained at the highest cutting speed The cut face finish can usually be improved by operating at slower speeds When speed is reduced to obtain improved surface finish, the preheat flo should be correspondingly decreased to prevent excessive melt-down of th top edge.

With multiple torch operations, the preheat effect and overall operation i basically similar to vertical cutting. Figures 42.7, 42.8 and 42.9 illustrate th different settings to obtain three basic edges. In each case, torch position var ables A and B are governed by plate thickness, nozzle size and speed of cutting Nozzles lead one another as much as is practical without interrupting the cuttin action of the three cutting oxygen streams. When dimensions A and B are to great, however, the cutting action does not continue beyond the kerf of th leading torch. This causes the oxygen stream to be deflected into the kerf an results in a gouging action, a rough surface and usually a light adherence o dross to the underside of the prepared edge.

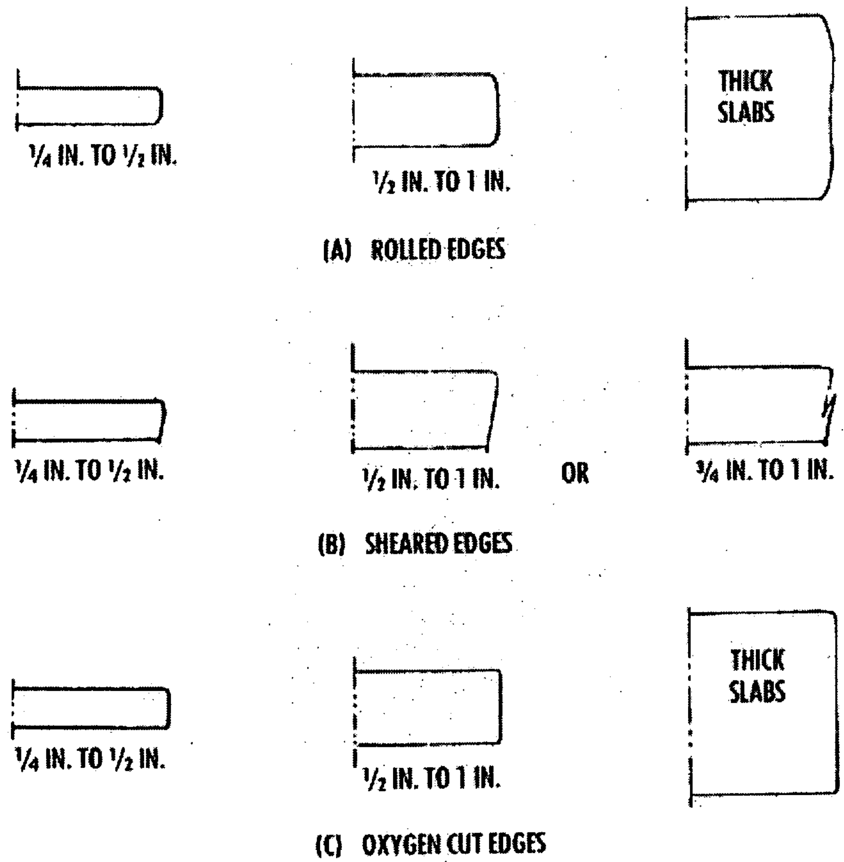


Fig. 42.6.—Typical rolled, sheared and oxygen cut edges.

The proper positioning of the torches in a lateral direction for multibevel cutting is usually accomplished by trial and error. This can be costly, resulting in lengthy reworking or possible scrap. The use of a simple machined template, which is typical of the desired edge geometry, is quite useful for torch alignment. A kerf-centering device is attached to each nozzle. The torches are then properly angled and adjusted to the edge template. The multitorch cutting head is now ready to duplicate the template profile (Fig. 42.10). In order to obtain close tolerances when preparing plate edges, precise conveying equipment is necessary. For reproducibility, accuracy and maximum efficiency, the large gantry and rail type equipment is available. Such apparatus may be classified in the same category as a machine tool. A plate can easily be located on the cutting bed. A 3-gantry type unit would be located at their respective positions and 4 sides of the plate are prepared concurrently. Camber and angular cuts are also producible. (Fig. 42.11).

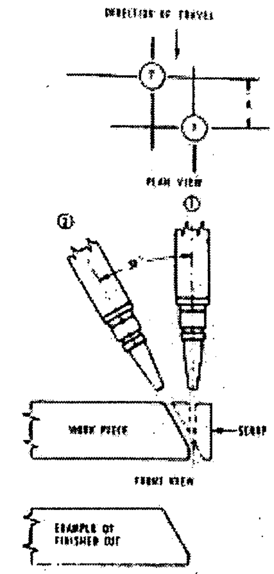


Fig. 42.7.—Multiple-torch machine o gen cutting procedure used in typ plate edge preparations.

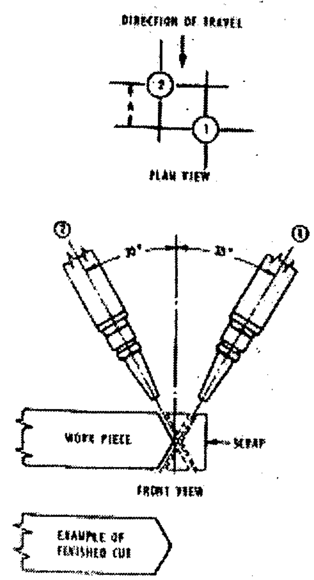


Fig. 42.8.—Two oxygen cutting torches employed in machine cutting and simultaneous plate edge preparations.

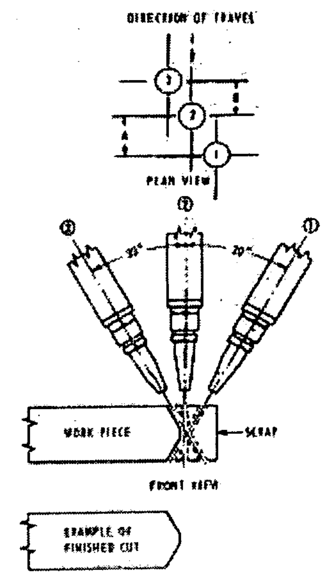


Fig. 42.9.—Three oxygen cutting torchu used to simultaneously sever and shaj a plate edge.

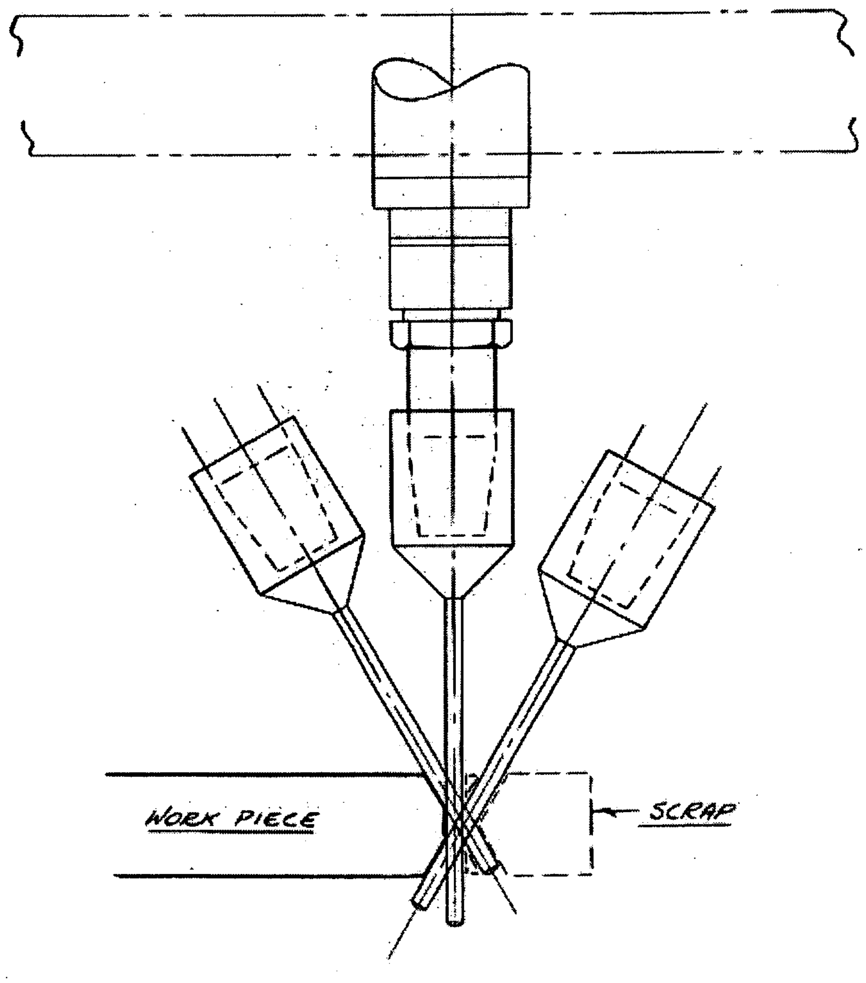


Fig. 42.10.—Kerf centering and bevel angle setting device.

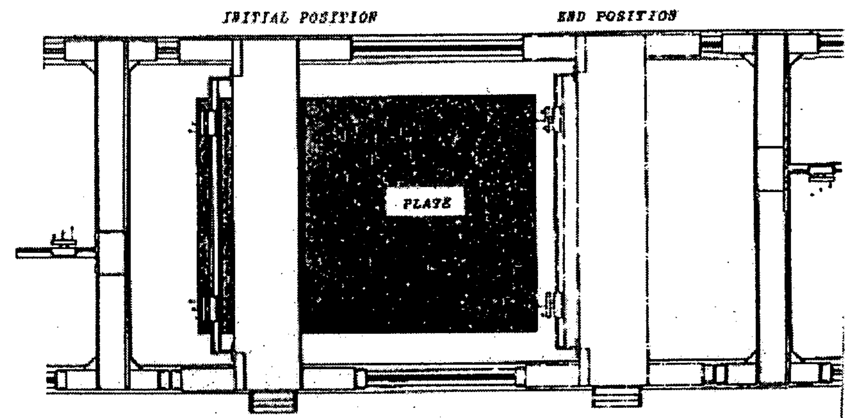


Fig. 42.11.—Portal type "S" Flame Cutting Machine.

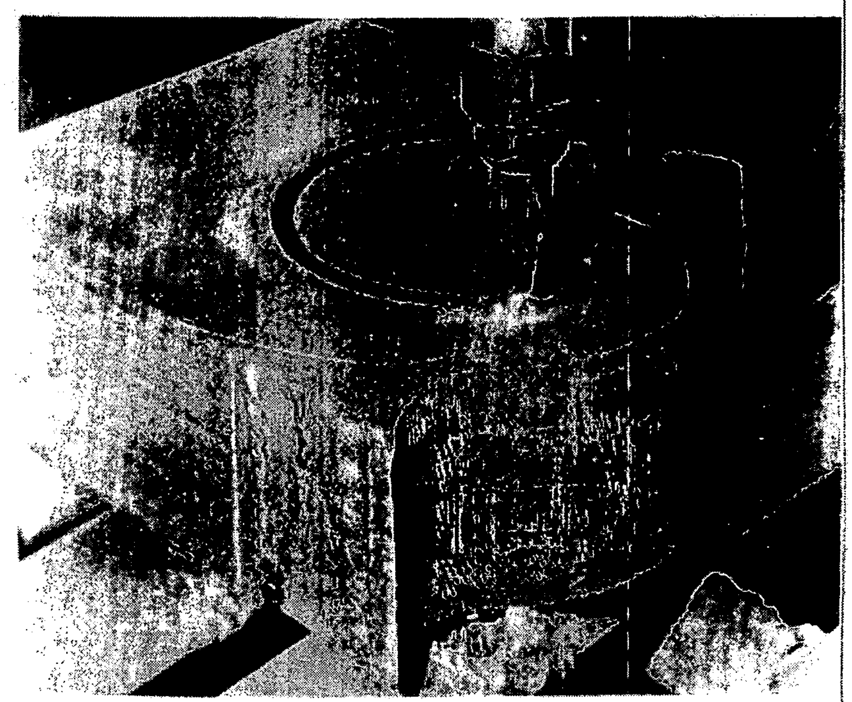


Fig. 42.12.—Typical stack cutting procedure (Note welding head to hold plates proper alignment.)

STACK CUTTING

Stack cutting is the cutting of multiple layers of material (each usually less than 1/2 in. in thickness) as though they were one thick piece of material. Stack cutting, properly prepared and executed, has many advantages to offer. Foremost is increased productivity at lower cost since both cutting time and fuel consumption are somewhat less than proportional to thickness cut. Also, the resulting patterns usually have edges that are highly stressed, squarer and more free of burrs, slivers and drag as compared to sheared plates. Fig. 42.12 illustrates a typical stack cutting operation.

It is of utmost importance that the stack be formed as nearly as possible into a solid slab. Sufficient clamps should be used to eliminate all air gaps, especially along the line of cut. Obvious conditions such as uneven, bent, buckled or warped material should be corrected or replaced. Sheared plates should be piled with the burred edges all facing the same direction. Foreign matter on the surface is generally removed by wire brushing followed by an air blast. Extreme cases might require pickling or sand blasting. To facilitate cut starts, consideration should be given to straight vertical alignment of one side of the stack.

The total thickness is generally determined by the required dimensional tolerance of the cut piece. Best tolerances are achieved at approximately 2 in. with a gradual deterioration up to 6 inches. When cut piece size permits, multiple torch stack cutting can be applied.

Even when extreme care has been exercised, there is always the possibility of a torch pop-out with, perhaps, loss of the entire stack. The application of flux cutting and powder cutting processes greatly minimizes this hazard. These combustible additives to the cutting stream assist in propagating the reaction down through the cut to the extent that appreciable air gaps that otherwise might inhibit cutting process continuity can be tolerated between plates. The use of divergent nozzles with high velocity cutting jets seems to aid this transfer action further. Another effect is that plate thickness need not be limited to 1/2 inch. Highly alloyed steels, including stainless, can now be stack cut. The extreme care required in preparing the stack has been lessened under certain conditions.

Regardless of procedure employed, the economy of a stack cutting operation must be carefully compared with the total costs involved, including such items as material preparations, stack makeup, clamping devices and increased skill and care requirements.

MATERIALS CUT

For most mild steel cutting, standard oxygen cutting equipment is satisfactory. For highly alloyed and stainless steel cutting, it may be necessary to use a special process such as flux injection or powder cutting (described in other sections of this chapter), or some of the newer arc cutting processes described in Chapter 43, "Arc Cutting." The cutting process and type of operation (manual or mechanized) selected depend on the material that is being cut and the ultimate use of the product.

Table 42.3—Data for manual and machine cutting of clean mild steel (not preheated)

Thickness of Steel, In.	Diameter of Cutting Orifice, In.	Cutting Speed, In. per Min.	Gas Consumptions, Cu Ft per Hour			
			Cutting Oxygen	Acetylene	Natural Gas	Prop[illegible]
1/8	0.020–0.040	16–32	15–45	3–9	9–25	3–[illegible]
1/4	0.030–0.060	16–26	30–55	3–9	9–25	5–[illegible]
3/8	0.030–0.060	15–24	40–70	6–12	10–25	5–[illegible]
1/2	0.040–0.060	12–23	55–85	6–12	15–30	5–[illegible]
3/4	0.045–0.060	12–21	100–150	7–14	15–30	6–[illegible]
1	0.045–0.060	9–18	110–160	7–14	18–35	6–[illegible]
1 1/2	0.060–0.080	6–14	110–175	8–16	18–35	8–[illegible]
2	0.060–0.080	6–13	130–190	8–16	20–40	8–[illegible]
3	0.065–0.085	4–11	190–300	9–20	20–40	9–[illegible]
4	0.080–0.090	4–10	240–360	9–20	20–40	9–[illegible]
5	0.080–0.095	4–8	270–360	10–24	25–50	10–[illegible]
6	0.095–0.105	3–7	260–500	10–24	25–50	10–[illegible]
8	0.095–0.110	3–5	460–620	15–30	30–55	15–[illegible]
10	0.095–0.110	2–4	580–700	15–35	35–70	15–[illegible]
12	0.110–0.130	2–4	720–850	20–40	45–95	20–[illegible]

Preheat oxygen consumptions: Preheat oxygen for acetylene = 1.1 to 1.25 × acetylene flow (cu [illegible] per hr); preheat oxygen for natural gas = 1.5 to 2.5 × natural gas flow (cu ft per hr); preheat oxy[illegible] for propane = 3.5 to 5 × propane flow (cu ft per hr).

Operating notes: Higher gas flows and lower speeds are generally associated with manual cutti[illegible] whereas lower gas flows and higher speeds apply to machine cutting. When cutting heavily scaled [illegible] rusted plate, use high gas flows and low speeds. Maximum indicated speeds apply to straight l[illegible] cutting; for intricate shape cutting and best quality, lower speeds will be required.

The oxygen cutting speeds given in Table 42.3 contain a great many va[illegible] ables. The flow and cutting speed data given are to be considered only as [illegible] guide for determining more precise settings for particular jobs. When co[illegible] pletely new material is being cut, a few trial cuts will be necessary to obta[illegible] the most efficient operating conditions. The flows and speeds indicated in Tab[illegible] 42.3 cover a fairly wide range and include most common practices using co[illegible] ventional equipment.

High pressure divergent nozzles will provide slightly faster cutting spee[illegible] with narrower kerf widths and produce equivalent high quality work. Cutti[illegible] oxygen head pressures up to 500 psi, with attendant cutting speed increase[illegible] have been used with good results. Extreme care must be exercised to preser[illegible] the original cutting orifice contour or the tip efficiency will be drastically r[illegible] duced. Only tip cleaning devices recommended by the tip manufacturer shou[illegible] be used.

It should be noted that the chart ends at 12 in., which is the maximum thic[illegible] ness normally encountered for shape cutting in production shops. The divisi[illegible] has been made arbitrarily. The cutting of steel plate over 12 in. thick is co[illegible] sidered heavy cutting. The characteristics of heavy cutting are given in anoth[illegible] section of this chapter.

OXIDATION-RESISTANT MATERIALS

The absence of alloying materials in pure iron exposes all the iron to oxid[illegible] tion by the oxygen cutting jet. As the amount and number of alloying materi[illegible] increase, the oxidation rate decreases from that of pure iron. The oxidati[illegible] of the iron in the alloy liberates a considerable amount of heat and produc[illegible] iron oxides, which have melting points near the melting point of iron. Howeve[illegible]

the oxides of many of the alloying materials have a melting point far higher than that of iron. These oxides, which produce refractory material, may shield the material in the kerf to such an extent that fresh iron is not continuously exposed to the oxygen stream. Because of these factors, the rate of cutting is reduced as the alloying elements in the iron, which produce high melting point refractory oxides, increase. For those ferrous metals with high alloy content, such as cast iron and stainless steel, variations in the normal oxygen cutting methods must be used.

Cutting Methods

There are at least six methods of cutting materials containing relatively large quantities of alloy materials, particularly alloying materials that, when oxidized, will produce refractory oxides. Chromium irons, stainless steels and cast irons are examples of these materials. Adequate safety precautions and measures should be taken to protect the operator and those in the immediate area from the exhaust products of the operation when cutting oxidation-resistant material, especially when using flux or powder.

Oscillatory Motion.—Refractory oxides may form when the cutting jet impinges on some materials. In these cases it becomes necessary to move the torch slightly to one side or the other so that new material can be heated to the ignition temperature and additional material oxidized and blown out of the kerf. If this oscillatory motion is accompanied by a progressive forward motion, continuous cutting can be accomplished. Where the cut has for its prime intention the severing of material, with no regard for quality, and where the time consumed in cutting is not a major factor, this is a reasonably satisfactory method (Fig. 42.13). This procedure does not require the use of auxiliary apparatus.

Combinations of this method with some of the methods described below have been used. These combined methods normally require special nozzles designed to obtain greater quantities of preheat gas, since the ability to make a progressive cut is greatly dependent upon heat transfer from the preheat flames to the material. In the cutting of cast iron, it is customary to use cutting nozzles that can supply greater quantities of preheat.

Waster Plate.—One of the earliest and best known methods of cutting these materials is to clamp a low-carbon steel plate along the upper surface of the material to be cut. On occasion, a welding bead of low-carbon steel is put along the line to be cut to obtain the same result. In these cases, the cut is started in the low-carbon steel material. The heat liberated by the oxidation of this material and the subsequent formation of a greater amount of iron oxide in the kerf makes it possible to accomplish progressive cutting. The thickness of the waster plate or weld bead must be in proportion to the thickness of the material being cut. This method has the disadvantage of either a large loss of plate or the necessity of applying the welding bead along the line of cut.

Wire Feed.—With suitable equipment, a short length of low-carbon steel wire can be fed into the preheat flames. Because of its shape, the end of the wire melts very quickly and the molten particles are rapidly oxidized and carried by the oxygen stream onto the plate being cut. The heat from the burning of these particles of wire rapidly brings the surface or face of the steel plate up to the ignition temperature and a progressive cut is readily made. This method can be

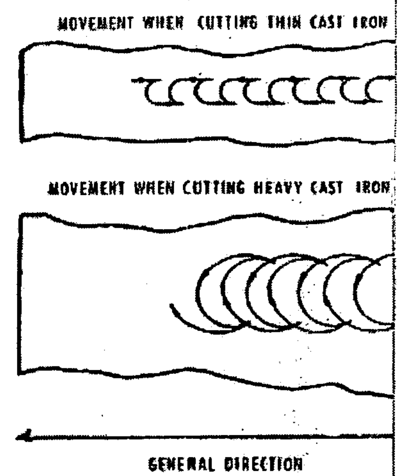


Fig. 42.13.—Typical cutting torch manipulation for cutting thin cast iron (top) and heavy cast iron (bottom).

used for starting cuts without stopping for preheating on carbon steels, a pro cedure known as a flying start. In the same way, oxygen cutting of hard-to-cu materials can be accomplished by continuously feeding iron wire into the cut ting jet. To be successful, this method requires specially designed attachment on the cutting torch for continuous iron wire feed.

Heating.—It is known that many materials that are difficult or almost impos sible to cut when cold can be cut with relative ease if they are heated to temper atures approaching the melting point of the material. Because of the temperatur of the surrounding material, the heat liberated by the cutting reaction add sufficient heat to the cutting zone to melt some of the refractory materials These materials can then be washed from the kerf. This solution, althoug normally impractical, can be used in special cases.

Oxygen-Arc Cutting.—Another method that has been developed is th oxygen-arc cutting process, wherein an electric arc is struck between a hollov carbon or carbon steel electrode and the work. A stream of oxygen is passe through the hollow core of the electrode. This process is covered in detail i Chapter 43, "Arc Cutting."

Flux Cutting.—In 1945, the flux cutting process was introduced. This proces was primarily intended for the cutting of stainless steels. The flux was designe to react with alloying materials, such as chromium and nickel, to produce com pounds with melting points in the temperature range of the iron oxides produce in the cutting of carbon steels. In this way the cutting of stainless steels can b carried out in one continuous movement with no need for oscillation or th addition into the oxygen cutting stream of anything other than the flux. Specia apparatus is required. By using the flux cutting method, cutting speeds approach ing those for cutting equivalent thicknesses of carbon steel can be attained. Th nozzle sizes will be larger and the cutting oxygen flow will be somewhat greate than are required for cutting an equivalent thickness of carbon steel.

Table 42.4.—Powder cutting data for stainless steel

Steel Thickness, In.	Diameter of Cutting Oxygen Orifice, In.	Oxygen Pressure, Psi.	Cutting Speed, In. per Min.	Gas Consumption, Cu Ft per Hr		Powder Flow, Oz. per Min.	Steel Thickness, In.
				Oxygen	Acetylene		
1/2	0.040	50	14	125	15	4	1/2
1	0.060	50	12	225	23	4	1
2	0.060	50	10	300	23	4	2
3	0.080	50	9	550	32	5	3
4	0.100	50	8	675	38	6	4
5	0.120	60	7	800	45	7	5
6	0.140	60	6	900	63	8	6
8	0.140	70	4	1000	63	8	8
10	0.160	75	3.5	1100	75	8	10
12	0.160	75	3	1200	75	8	12

Table 42.5—Data for heavy cutting

Thickness of Steel, In.	Oxygen Flow, Cu Ft per Hr	Diameter of Cutting Orifice, In.	Cutting Oxygen Pressure at Torch, Psi
12	1000-1500	0.147-0.221	26-56
16	1300-2000	0.1935-0.290	25-49
20	1600-2500	0.200-0.221	25-48
24	1900-3000	0.221-0.332	22-48
28	2200-3500	0.230-0.400	18-44
32	2500-4000	0.250-0.450	16-40
36	2900-4500	0.290-0.500	12-38
40	3400-5000	0.330-0.550	10-33
44	3800-5500	0.375-0.550	9-29
48	4500-6000	0.422-0.600	7-27

Powder Cutting.—In 1944 the powder cutting process was introduced for the cutting of most hard-to-cut metals. The powder process is a general term used to describe a technique for supplementing an oxy-fuel gas torch with a stream of powdered material. This material accelerates and propagates the oxidation reaction and the melting and spalling action of hard-to-cut materials. Powder operations may be performed with conventional cutting torches and nozzles. The powder is introduced into the reaction zone either through the nozzle or by means of single or multiple jets external to the nozzle or tip (Fig. 42.14). When the former method is used, the gas-conveyed powder is introduced into the cutting stream prior to its discharge from the nozzle. When the powder is introduced externally, the gas conveying the powder imparts sufficient velocity to the powder particles to carry them through the preheat envelope into the cutting oxygen stream. The short time in the preheat envelope is sufficient to produce the desired reaction in the cutting zone.

Some of the powders used are intended to react chemically with the refractory oxides produced by the oxygen jet. The resultant slags of lower melting points remain fluid and are washed out of the reaction zone. Unoxidized metallic surfaces are thus exposed and presented to the oxygen jet. Metallic powders such as iron powders may be employed. These powders burn and thus liberate additional heat in the reaction zone; this keeps the refractory oxides molten. The additional quantity of iron oxide produced results in the formation of a slag matrix, which carries the refractory oxides out of the reaction zone. The cutting of some materials may require mixtures of metallic powders such as iron and aluminum. This requirement exists where greater quantities of heat are needed to keep the oxidation melting and spalling reactions proceeding at the desired rate.

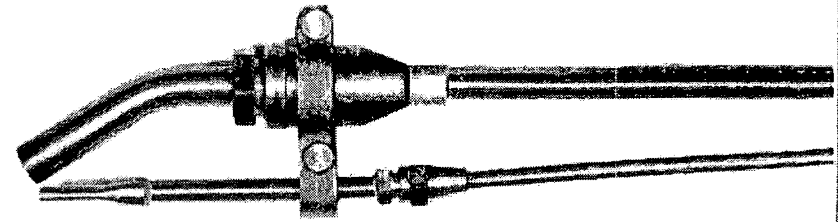


Fig. 42.14.—Close-up of a typical washing tip with an iron powder nozzle.

Operations on hard-to-cut materials, usually proceed at slower rates of spe with the same or slightly greater oxygen flow rates than are required for cutti equivalent thicknesses of ordinary carbon steel plate. Table 42.4 contains powd cutting data for AISI 302 steel. In this process, powdered iron or mixtures powdered iron and other powdered materials are introduced into the reactio zone.

Powdered iron begins to burn when introduced into the cutting zon thereby liberating a tremendous amount of heat in addition to that supplied b the normal preheat flames. This heat tends to melt at least some of the oxid that may be formed on the cut surface. Two other effects occur simultaneousl The principal one is that the iron oxides produce a matrix of iron oxide whic is sufficient to flush away the refractory oxides that are formed. The secon effect is that the presence of the iron powder or the burning oxides in the cuttin stream, coupled with the kinetic energy of the resulting stream, increases th mass velocity of the cutting jet. This results in a combination of erosion and, i effect, shot blasting of the cut surface, thereby continuously exposing a fres surface to the cutting stream. Cutting of difficult-to-cut materials by the powde method can be accomplished at the same speeds as oxygen cutting of carbo steel of equivalent thickness. However, the cutting oxygen flow is slightly highe with the powder process.

Equipment for Cutting Oxidation-Resistant Materials

Powder and flux cutting require several pieces of apparatus in addition t the torches and tips. Flux cutting employs a standard torch and tip, where powder cutting may employ a standard torch and tip with an auxiliary attac ment. A powder dispenser and a gas supply to the dispenser are required for th powder process. The gas used for powder dispensing may be compressed ai nitrogen or other inert gas, or a special gas mixture. An additional hose fo transporting the powder from the dispenser to the torch is also required.

Flux Cutting Equipment.— With the flux process a flux feed unit is require The cutting oxygen is passed through the feed unit and this transports the flu to the torch. No auxiliary fluxhose or attachment is required.

In the flux cutting process a flux is held in a dispenser, which is a pressu vessel for use at the cutting oxygen pressures normally employed. The cuttin oxygen flow through the dispenser is adjusted by means of a regulator. The flu at rates of flow prescribed by the manufacturer, is transported by the cuttin oxygen from the dispenser through a hose to the cutting torch. This torch utiliz three hoses. One hose supplies the preheat oxygen, the second, acetylene o other fuel gas in the conventional manner, and the third, the flux and cuttin oxygen. The preheat gases are mixed as in standard oxyacetylene or oxy-fu

gas devices. The preheat gases are delivered to the tip and burn at the exit face of the tip through a multiplicity of orifices. The cutting oxygen is turned on in the conventional way by depressing a lever, which opens the cutting oxygen valve. The lever is arranged so that depressing it also opens the valve in the flux line. The flux is in the cutting oxygen stream, so that a mixture of oxygen and flux issues from the tip.

Powder Cutting.—Dispensers for powder for the powder cutting process are of two general types. In each case, the dispenser includes a pressure vessel that operates at relatively low pressure.

One type of dispenser is a vibratory device in which the quantity of powder being dispensed from the hopper is governed by a vibrator. Varying amounts of powder can be obtained by changing the amplitude of vibration. The powder discharged from the vibrating device is dropped into a funnel-like arrangement. This funnel is within a sealed chamber. The powder conveying gas enters at this point, entrains the powder that has been dropped into the funnel and carries it through the hose to the torch. The size of the hose between the dispenser and the torch is important in order to entrain the powder with sufficient gas velocity but at the same time keep the ratio of conveying gas to powder as low as possible. The vibratory type of dispenser is generally used where uniform and accurate powder flow is required, such as in precision cutting, when shape cutting is to be done on materials such as stainless steel or when it is necessary to maintain high-quality, sharp top edges and other characteristics of conventional cutting.

The other type of dispenser, more in general use, is a completely pneumatic device and comprises a pressure vessel operating at relatively low pressure. In the bottom of this vessel is an ejector or fluidizing unit. The conveying gas is brought into the dispenser in a way serving to fluidize the powder so that it will flow regularly and easily into the ejector unit, where it will be picked up by the portion of the gas stream that serves as the transporting medium. The size of the connecting hose or conduit is important in that an effort is made to maintain a low transporting gas-to-powder ratio.

Whether a two- or three-hose machine cutting torch or a two-hose manual torch is used, an additional hose is required for powder. The special manual powder cutting torch brings the oxygen and acetylene or oxygen and fuel gas to the torch, mixes them and then discharges this mixed gas through a multiplicity of orifices in the cutting tip as in a conventional oxyacetylene torch. The powder valve is built as an integral part of the torch. The cutting oxygen lever that, when depressed, would normally turn on the cutting oxygen is so arranged that it also opens the powder valve in proper sequence. The powder entrained by the conveying gas is then brought through a separate conduit into a chamber forward of, and sealed off from, the preheat gas chamber in the torch head. This powder then enters a separate group of passages in a two-piece cutting tip and is discharged at the mouth of the tip in a conical pattern. The powder is discharged with sufficient velocity to cause it to enter and pass through the envelope of burning preheat gas and surround the cutting oxygen stream that issues from the central orifice in the tip. The tip passages conveying the powder are constructed from materials that can resist the abrasion of the gas borne particles. Similarly, the torch head, connecting tubing and all the other parts of the torch that are subject to abrasion by the powder must also be made of materials that will have relatively long life in this type of service.

Powder cutting adaptors are available for machine cutting or for adaptati
of conventional two-hose manual cutting torches. Thus standard machine c
ting or manual cutting torches may be used together with standard oxyacetyle
or oxy-fuel gas cutting tips. In these cases, the powder valve is opened or clos
by a completely separate motion from that required for opening the cutti
oxygen valve. The gas powder mixture is carried from the downstream si
of the powder valve to a powder cutting adaptor attached to the cutting ti
This adaptor surrounds the periphery of the exit end of the tip; the seve
powder passages cause the powder to issue in the form of a cone and at su
cient velocity to blow through the preheat envelope and impinge against t
cutting oxygen stream. In a great many cases, particularly for manual cutti
or straight line machine cutting, the powder cutting attachment is eliminat
and a single tube is substituted. This tube discharges the powder-laden stre
at an angle to the cutting oxygen jet at a velocity sufficient to drive it throu
the preheat envelope. This single tube attachment is applicable only wh
cutting is being done in one direction, for the powder tip must in all cases
at the leading or front edge of the cutting oxygen stream.

When the above methods are used for cutting oxidation-resistant meta
the quality of the cut surface is somewhat impaired. Dross adherence m
occur. Carbon and iron pickup usually occurs in stainless steel and other nic
alloy materials, thus lowering the corrosion resistance and non-magne
properties of the base metal. In order to retain the corrosion-resistant a
non-magnetic properties of these materials, it is accepted practice to remo
mechanically approximately ⅛ in. from the cut edge.

Fast-Starting Powder.—Ordinary cutting torches and nozzles may be equipp
with external powder feed nozzles. Instantaneous starts can be accomplish
with this equipment at the normal cutting speed by using a burst of pow
when the leading edge of the cutting oxygen stream impinges against the pie
being cut. After the cut has been initiated on carbon steel, the powder can
turned off, and the cut will progress in the conventional manner.

UNDERWATER CUTTING

Underwater cutting is used for salvage work and for any cutting that m
be done below the water line on piers, dry docks and ships. The two meth
most widely used are flame cutting and oxygen-arc cutting. The equipm
and operating techniques of the latter are described in Chapter 43.

The technique for underwater cutting is not materially different from t
used in cutting steel in open air. The torch used embodies the same featu
as a standard cutting torch, with the additional feature of supplying its o
ambient gas atmosphere. In the underwater cutting torch, fuel gas (other th
acetylene) and oxygen are mixed together and burned to produce the preh
flame, and a cutting jet is provided to supply the oxygen to cut the ste
The additional design requirement of the underwater torch is that provisi
must be made for maintaining an air bubble around the cutting tip. The
bubble is maintained by delivering compressed air to the torch; this co
pressed air is ejected around the tip, sheathing it in a bubble of air, or
artificially created atmosphere in which the tip can function normally. The
shield stabilizes the flame and at the same time displaces the water from
cutting area, permitting more efficient heating of the steel, since water i
far better conductor of heat than is air.

The underwater cutting torch is furnished with connections for three hoses to convey compressed air, fuel gas and oxygen. In addition, a combination shield and spacer device is attached at the end of the torch. The shield controls the formation of the air bubble and is also adjustable, so that the tip can be held at the correct distance from the work. This second feature is essential for underwater work where the torch is employed under adverse lighting conditions by operators wearing cumbersome diving suits that preclude the possibility of using a torch without a means of mechanically holding the torch at the optimum distance from the steel. Slots in the shield are provided to allow the burned gases to escape to the surface. A short torch is used to reduce the recoil accompanying the release of the gas jet against the surrounding water. Fig. 42.15 shows a cross-section of a typical torch.

As the cutting operations go deeper, the gas pressures must be increased to neutralize the added water pressure as well as the frictional losses in the longer hoses. Approximately ½ psi for each foot of depth should be added to the initial working pressures. Hydrogen and natural gas are the best all-purpose preheat gases since they can be forced to any depth that a diver can descend and still remain gaseous. Although most other gases normally associated with flame cutting can be used, they are usually restricted to shallower depths.

The oxy-fuel gas cutting torch experiences no great difficulty in progressively severing steel plate in thicknesses from ½ in. up to about 6 inches. Under ½ in., however, the constant quenching effect of the surrounding water lowers the efficiency of preheating to the extent that cutting speeds are substantially retarded. It is on this thin material that the oxygen-arc cuting process works well. Although the oxygen stream issuing from the electrode has no precise form for penetration, it washes the metal away under the intense heat of the arc. This feature also permits it to sever cast iron, brass and other nonferrous metals. There are, however, the ever-present hazards involved when handling high-amperage current.

Both processes have a definite application and each should be given careful consideration on specific jobs in order to use the diver's time effectively. For more details refer to "Underwater Cutting and Welding Manual" Navships 250-692-9 (1953).

HEAVY CUTTING

Heavy cutting is defined, for purposes of this chapter, as the oxygen cutting of steel over 12 in. thick and ranging upward to 94 in. or more. The art of heavy cutting was given a tremendous boost by the mandatory use of oxygen cut steels caused by the demand for rapid production of heavy steel items, especially heavy forgings, during World War II. The development of equipment for heavy cutting during the war period was followed in the late 1940's by controlled studies of the process. These events have resulted in putting heavy cutting applications on an orderly and predictable basis.

Results of technical studies under controlled conditions, backed by more than twenty years of field use, have shown how to do heavy cutting on a repetitive basis. The most useful observation from this experience is that the basic reactions permitting oxygen cutting of heavy steel are the same as those for cutting of thinner sections. Thus, materials ranging in thickness from ¼ in. to 94 in. may be cut, with preheat and cutting oxygen flows increasing and cutting speeds decreasing as thicknesses increase.

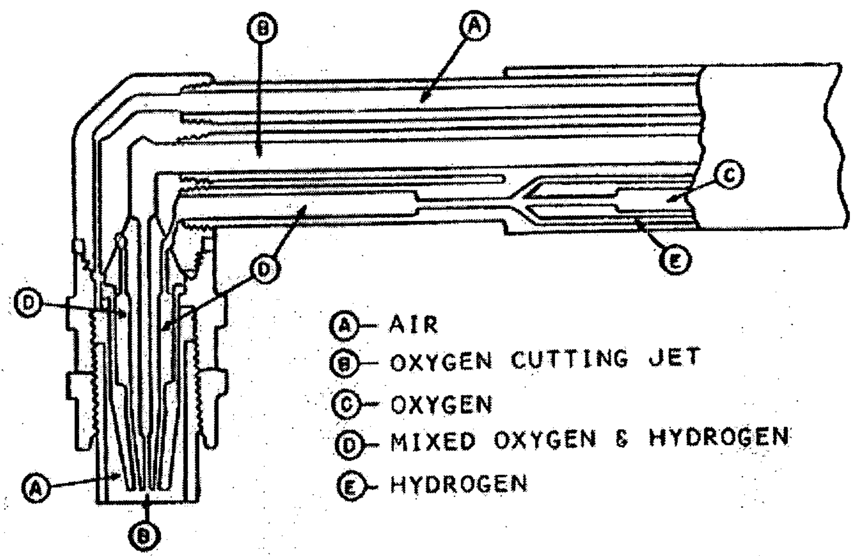


Fig. 42.15.—Operational functions of gases in underwater cutting torch.

For heavy cutting, the most important factor is oxygen flow. Nozzle size and operating pressure are involved only insofar as these values must provide the necessary flow required for the thickness being cut. Oxygen cutting pressures in the range of 7 to 50 psi, measured at the entry of the cutting torch, have been found adequate for the heaviest cutting attempted (up to 94 in.) provided that the nozzle size and equipment are properly selected. The oxygen flow at the torch entry is of paramount importance in comparing results of different cutting operations. Measurements of pressure at the regulator or at some point removed from the torch, without regard to restrictions nearer the nozzle, will lead to much confusion. Unknown restrictions cause variations in flow and unpredictable results when conditions are not exactly duplicated. By predicting performance on the basis of flow rather than pressure, heavy cutting data can be plotted as a continuous curve.

In terms of flow it is possible to arrive at an approximate demand constant that will be useful as a guide in selecting equipment suitable for a given job. These demand constants may vary, but in terms of thickness they usually fall within the approximate range of from 80 to 125 cubic feet of oxygen consumed per inch of thickness (80T to 125T, where T is thickness in inches). Table 42.5 gives the range of operating conditions that cover normal heavy cutting operations. Heavy cutting covers a wide variety of operations, such as ingot cropping, scrap cutting and riser cutting. It must therefore be understood that the data obtained from this table may not be entirely suitable for all heavy cutting operations, although these values have been used successfully.

They may be used as a guide in selecting the correct equipment and operating conditions. The actual values for most efficient operations of the specific cutting application involved are always best found by trial cuts.

When heavy cutting is performed with the torch in a horizontal position, the cutting oxygen pressure may have to be increased to aid in mechanical removal of the slag produced from the cutting reaction.

Recommendations as to the speed of travel are not included in Table 42.5 but speeds from 2 to 6 ipm are used in the range of thicknesses covered. A speed of 3 ipm is possible for thicknesses up to at least 36 inches. The correct speed is obtained by observing the operating conditions carefully and making suitable adjustments when actual cutting is in progress.

Because heavy pieces usually present an irregular, scale-covered surface, techniques of starting the cut differ from those usually used with thinner material where the edges are frequently square and clear of scale. The start of the reaction is made more slowly on the rougher edges, but the reaction, once started, is more marked and spectacular because of the greater volume of iron being oxdized per unit of time. Fig. 42.15 indicates correct and incorrect starting conditions. Fig. 42.15A shows the desirable starting position with the flow of molten metal extending down the face of the material rather than lying on the top. This flow of molten metal permits the cutting reaction to proceed down the face of the material to the bottom as the oxygen is turned on and forward motion is started. Fig. 42.16B, C, D, E, and F show problems occurring from incorrect procedures.

When the cut proceeds properly, with correct oxygen flow and forward speeds, the reaction will proceed to the end of the cut, without leaving a skipped corner. Fig. 42.17 illustrates various correct and incorrect terminating conditions and proper drag conditions. Conditions producing a drop cut are depicted in Fig. 42.17A.

In general, the conditions required for successful heavy cutting on a production basis are:

1. An adequate gas supply sufficient to complete the cut. This is necessary as a lost cut on heavy materials is extremely difficult, if not impossible, to restart at the lost cut surface.
2. Equipment of sufficient size structurally (to maintain rigidity and to carry the equipment needed) and of sufficient capacity to handle the range of speeds and gas flows required.
3. Skilled personnel trained in proper heavy cutting techniques.

The first item is important to ensure completion of the job without interruption due to insufficient gas capacity. Not only must the gas source be adequate, but the pipe lines, station drops and regulating equipment must be of a size suitable for the gas flows to be handled. Table 42.5 shows that oxygen flows for heavy cutting are in the range normally supplied only by pipe line with well-engineered facilities. Design of the gas supply should emphasize lack of restrictions so that full flow is maintained at the cutting nozzle at all times.

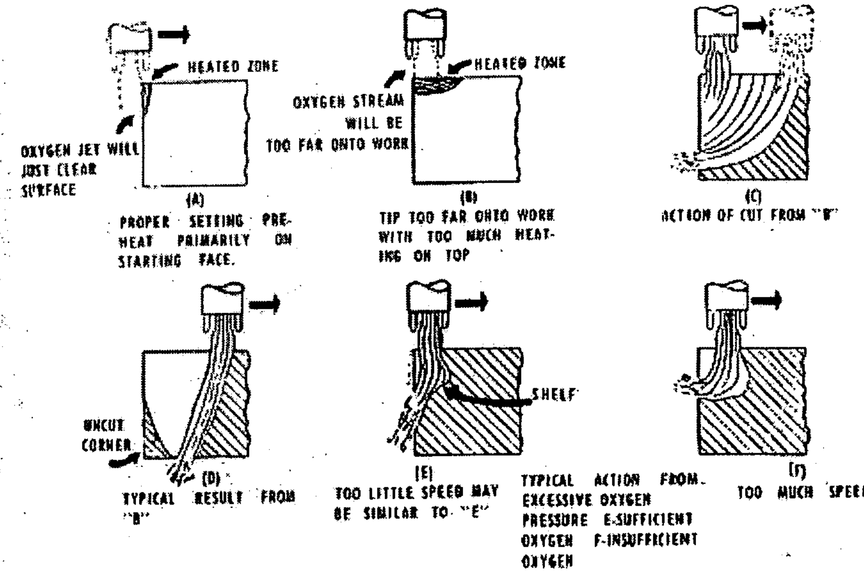


Fig. 42.16.—Typical conditions for heavy cutting.

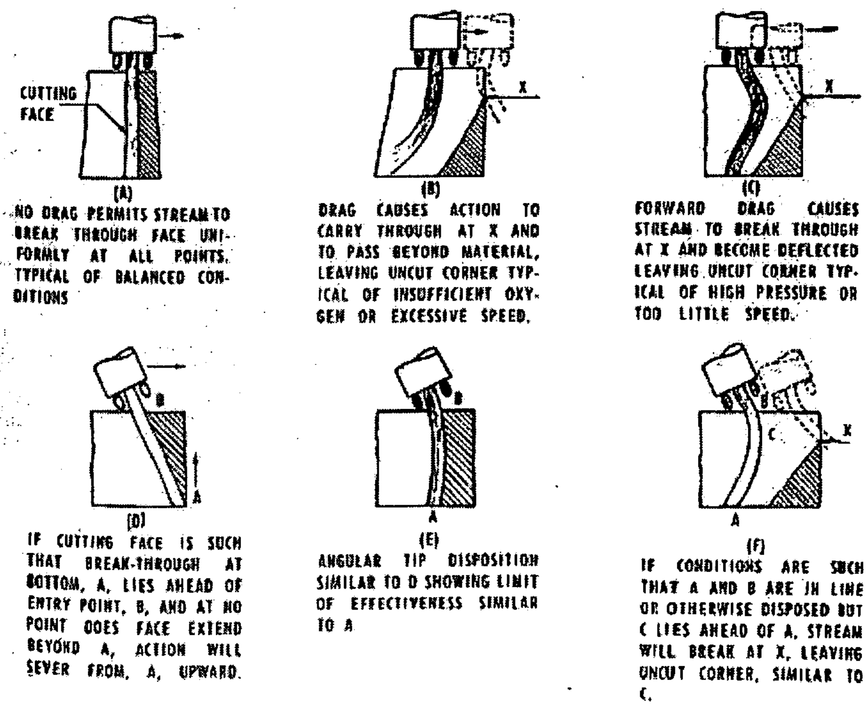


Fig. 42.17.—Terminating conditions for heavy cutting.

The cutting equipment and machines must also be selected for the particular job under consideration. The machines used to carry the cutting torches must be strong and rigid enough to carry the load of the cutting torches and the supply hoses, and should be properly counterbalanced where necessary. These precautions are essential for the safety of operating personnel and to maintain continuity in the cutting operation. The machines must be capable of maintaining a uniform speed and be geared to provide a minimum constant speed down to 1 ipm or less. Speed must also be readily adjustable so that it can be varied when cutting operations warrant.

Torches must be constructed with a minimum of internal gas flow restrictions. For cutting materials up to about 20 in. thick, torches with attached valves can be used satisfactorily, but for heavier work valveless torches are preferred. These permit locating control valves away from the heat of the cutting operation. Torch gas capacity for very heavy cutting should be a minimum of 6000 cfh at a maximum torch entry pressure of 20 psi for cutting oxygen and 300 cfh for the fuel gas; preheat oxygen capacity depends on the type of fuel gas employed.

Cutting nozzles designed specifically to provide preheat flames suitable for heavy cutting are essential for success. Preheat flames must be relatively large, or complete penetration will not be obtained and excessive drag will occur. No attempt should be made to obtain zero drag since this may tend to promote shelving; a drag commensurate with the thickness being cut should be sought.

The flame adjustment for heavy cutting should be a very long, slightly carburized flame so that much of the heat energy release takes place down in the kerf. Fuel gases that have a high heat release in the secondary portion of the flame usually produce the best results.

Trained personnel are essential for successful heavy cutting. They should be thoroughly familiar with the equipment and its control and should have no hesitancy about attempting heavy cutting operations. The cutting machine operators should be trained to be painstaking and exact in their work and to make accurate setups and alignments. A misalignment of a fraction of an inch, which would be of no consequence in thin sections, could become so exaggerated when dealing with thick sections that an expensive piece of steel could be ruined. Cuts up to 94 in. deep have been made in forging and scrap cutting operations.

The well-trained cutting machine operator, when starting a cut, knows that many variations in cutting conditions can be encountered; he also knows that proper and immediate adjustments to compensate for altering conditions will ensure consistently successful cuts. Finally, the cutting machine operator should wear proper clothing and protective devices at all times. (Refer to Section 1, Chapter 9, Sixth Edition of the *Handbook*.)

CUTTING AT ELEVATED TEMPERATURES

Continuing demands for greater production in the steel industry have increased the use of improved equipment for oxygen cutting of steels at rolling mill temperatures of 1500 to 2000°F (816 to 1093°C). Hot cutting is used to advantage directly in the rolling line, where the flexibility and low capital cost of the process have encouraged its use in place of mechanical shears, saws and other severing devices. It is also finding application in cutting billets produced by continuous casting processes. Even the relatively slower speed of the oxygen cutting process is compensated for by multiple torches or other means, whereas the currently available, low-cost oxygen and natural gas in steel mills have made operating costs of oxygen cutting in the rolling mill competitive with shear and saw costs.

To permit the inherently greater speeds of oxygen cutting at elevated temperatures, gas flows considerably greater than those used for cold cutting must be supplied. Cutting equipment (machines, torches and regulators) must be of sufficient capacity and size to handle these larger gas flows, as well as the severe thermal and operating shocks such equipment is subjected to under mill operating conditions. Torches must be selected for large gas flows, which must also be remotely controlled. All equipment, including the machine, hose, etc., should either be protected from or capable of exposure to the heat from the high-temperature material. Water cooling of the torch itself is generally necessary. Adequate safeguards to protect the operating personnel from intense heat, flying slag and scale must be provided during a hot cutting operation.

Oxygen cutting at elevated temperatures follows the same general principles that apply to cold cutting except for the great increase in the speed of reaction and, therefore, cutting speeds.

Very high cutting speeds can be obtained in the oxygen cutting of steels at elevated temperatures with some variations in the flatness and squareness of the cut faces. Choice of the most desirable cutting speed to be used for any given cutting application will depend on a proper balance of gas costs, quality of cut desired and requirements of the mill cycle being serviced by the cutting operation. Since elevated temperature cutting of steel permits a much wider range in cutting speeds, it also permits a wider choice of quality of cut surface—from very rough to very smooth. It is possible to make cuts on steel at elevated temperatures that are equivalent in finish and dimensional tolerance to quality cuts on cold material of the same thickness; however faster cutting speeds are used.

Whenever cut surface requirements are not rigid, the cutting speeds realized at elevated temperatures are much greater than those obtained on cold material. For many applications, rough cuts are not of major importance, and the advantages to be gained by increased cutting speed make very high speed cutting at elevated temperatures advantageous.

Both standing starts and flying starts are possible with elevated temperature cutting. However, a very heavy preheat, additional heat in the form of a leading auxiliary preheat or the introduction of a steel rod or iron powder at the point of flame impingement on the steel may be required to accomplish flying starts.

Carbon and other alloying elements in steels have a marked effect on cutting speeds, but very little investigative work has been reported. In one study it was found that maximum cutting speeds are obtainable in steels having about 0.75% carbon. Since the effects of alloying elements on oxygen cutting are insufficiently known, no specific statements can be made.

Metallurgically, hot cutting results in a cut surface free of carbon enrichment, and with scarcely perceptible hardness gradient; the thermal gradients produced are not of sufficient magnitude to cause pronounced carbon migration toward the cut surface. The cut edge shows evidence of a slight decarburization, mainly in the areas immediately under the preheat flames. Photomicrographs show that grain growth along the cut surface is not appreciable. Hot cutting with the correct procedure results in perfectly sound material with normal structure and no indication of thermal checking or other undesirable features.

Kerf widths obtained for quality cuts of elevated temperatures can be almost identical with those obtained in cold cutting, provided proper cutting nozzles are used. Quality cuts at elevated temperatures can be made with preheat controlled to a degree such that meltdown of the upper edge is only slightly more pronounced than in cold cutting. The intensive preheat used in making lower quality cuts at elevated temperatures results in a noticeable meltdown of the top edge. At temperatures encountered in hot cutting, it should be noted that the tenacity of slag and scale is increased and may cause difficulty in later forming operations if the cut face is irregular.

EQUIPMENT

There are two basic types of oxygen cutting equipment, manual and machine equipment. The manual equipment is used primarily in scrap cutting, cutting risers off castings and other cutting operations that do not require a high degree of accuracy. Machine cutting equipment is utilized where a large volume of cutting is performed, such as in steel fabricating shops. Oxygen cutting equipment varies in appearance, but both types operate on the same principle.

MANUAL EQUIPMENT

For manual cutting, a torch that can be manipulated readily is preferred. Manual oxygen cutting torches are available in various sizes. Torch selection generally depends on the thickness of the steel to be cut. Tips used in manual cutting equipment are of varied design, depending on the type of work to be done. For example, for cutting rusty or scaly steel, a tip furnishing a great amount of preheat would be selected. Such a tip can easily be installed in a standard cutting torch.

There are two types of torches: the tip mixing type, in which the fuel and preheat oxygen for the heating flames are mixed in the tip; and the premixed type, in which the mixing takes place in the head or at some location upstream of the head (for example, in the body of the torch). If both the oxygen and fuel gas are under appreciable pressure, the torch is designated as a positive pressure type (Fig. 42.18). When the fuel gas is at a lower pressure, generally a fraction of a pound per square inch, and supplied to the flames through the aid of an injector, the torch is designated a low-pressure or injector torch (Fig. 42.19).

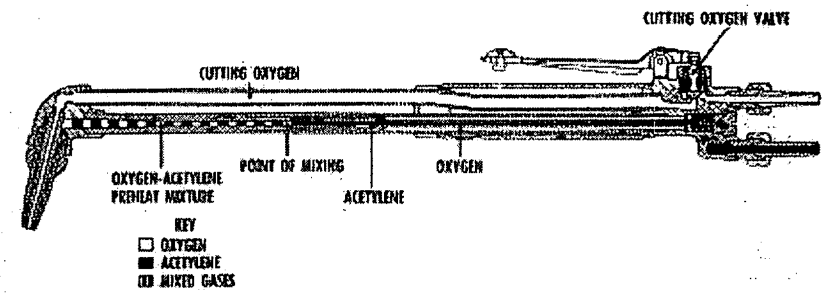


Fig. 42.18.—Schematic diagram of a positive pressure oxygen cutting torch.

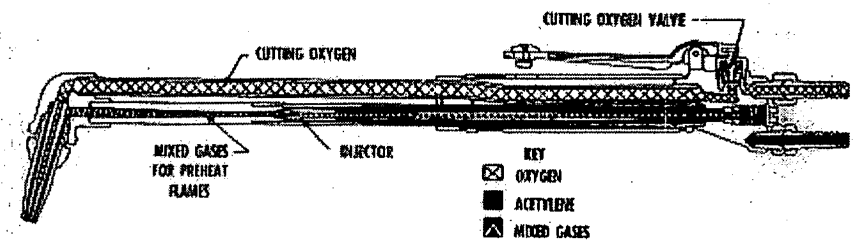


Fig. 42.19.—Typical premixed injector-type oxygen cutting torch.

The torch is connected to the gas supply by hose lines of sufficient size to conduct the volume of gases necessary for the cutting operation without excessive pressure drop. The hose lines are in turn connected to the outlet of the two pressure regulators (one for the fuel gas and one for the oxygen), which in turn are connected to the respective gas supplies, which may be a pipe line, a manifold or a cylinder.

MACHINE EQUIPMENT

Oxygen shape cutting machines are either portable or stationary. Portable machines are usually moved to the work, whereas the stationary machines are fixed in location and the work is moved to the machine.

The basic characteristics of stationary machine oxygen cutting are: a machine designed for the job, an operator station with complete electrical controls, a gas system to provide adequate quantities of oxygen and fuel gas and a materials handling system. Given a combination of these factors, machine oxygen cutting can be done with complete predictability.

Stationary oxygen cutting machines are usually classified in respect to the maximum width of the plate that can be cut, such as 60, 80, 120, 144 inches. Since most oxygen cutting machines run on tracks, the cutting length can be extended indefinitely.

An operator's station with consolidated controls for all the gases and the torch and machine movements is desirable and is usually designed as a part of the machine

Portable

Portable machines are used predominantly for straight line cutting, although they can be adapted for circular and some even for shape cutting. Portable machines usually consist of a motor-driven carriage with an adjustable mounting for the torch. In most cases the machine travels on a track, which performs the function of guiding the torch along the line of the cut, and which can be extended indefinitely. The speed control in these machines is adjustable over a wide range and controlled by a governor to maintain a uniform speed of travel. The degree of precision in following the line of cut depends upon the track or guide and the fit between such a guide and the driving wheels of the machine. Portable machines are of various weights and sizes, depending on the type of work to be done. The smallest machine weighs only a few pounds and is limited to carrying light torches for cutting thin material. The larger portable cutting machines are heavier and more rugged and can carry heavy torches and auxiliary equipment. The intermediate range machines are the ones generally used for miscellaneous straight line cutting and possibly circle cutting in the plate and general fabricating shop. The heavy-duty machines are used in fabrication shops, shipyards, steel mills and other areas where very thick steel sections are to be cut.

Stationary

The stationary type of cutting machine is designed to remain in a single location with the work being moved to the machine. These machines run on tracks with structures that either span the work with a gantry-type bridge or reach over the work with a cantilever device (Fig. 42.20). Stationary oxygen cutting machines may be classified into two main types:

1. Straight line cutting machines for plate edge preparation; these are often referred to as oxygen planners and are considerably heavier and of more rugged construction than the small portable machines.
2. Shape cutting machines which are capable of cutting any type of shape.

Straight line oxygen cutting machines usually span the plates, with either torch assemblies between the rails for edge preparation or several single torches for cutting steel strips in varying widths. Some types of oxygen cutting machines have lighter construction bridges that carry cross cutting carriages. With three such bridges, it is possible to cut all four sides of a plate at the same time. Torch assemblies used in the oxygen cutting machines for plate edge preparation are usually of the three-torch type, with wheeled carriages riding on the plate surface or with some other sensing means for maintaining a constant distance between torch tip and plate. The torch assemblies are generally arranged so that the torches can be angled with respect to each other for cutting bevels. Three-torch assemblies are capable of cutting two bevels and the root face in one operation.

Shape cutting machines are of two basic designs, one a pantograph and the other a cross-carriage mechanism. In both types of machines the basic element is a floating bar with a torch or torches located on one end and a tracing or driving device on the other. The differences in design are in the portions of the machine that carry this bar.

Fig. 42.20.—Typical gantry-type oxygen cutting machine.

In the pantograph-type machine, the bar is held by two arms that fold open and shut. The entire pantograph assembly is mounted on a carriage riding on rails which can be of any desired length.

In the cross-carriage mechanism, the carriage also rides on rails. The bar holding the torches can easily move at right angles to the longitudinal carriage on which it rides. Both designs can cut regular or irregular shapes of nearly any complexity and size. Shape cutting machines can mount numerous torches, depending on the size of the machine. Ten or more torches may be used in normal operations. In multiple-torch operations as many identical shapes can be cut simultaneously as there are torches (Fig. 42.21).

TRACING DEVICES

As indicated in the previous section, the usual type of oxygen shape cutting machine employs a bar with torches on one end a tracing device on the other end. On some machines this bar is driven at cutting speeds by a small wheel riding on the tracing table. A suitable tracing device is combined with the driving wheel to steer the torch bar around a template or drawing of the part to be cut. Both the pantograph and rectilinear machines use the same tracing and drive principles. A small wheel or magnetic tracer is employed to drive the machine. The tracing device and arm may be manually guided around the outline of a drawing, may follow a vertical strip pinched between two drive rollers or trunnions or may be a magnetic tracer which adheres to and follows the outline of a steel template. An electronic tracing device may also be used, here a photocell follows the outline of a drawing and steers the driving wheel. Traction for driving the machine comes solely from the tracing wheel. The most recent designs for rectilinear type machines utilize a sine-cosine relationship. The carriage and the cross-arm, each with its own driving motor, are driven in the desired direction, but the speed of movement of the tracing arm remains at the constant preselected value. This construction allows the manufacture of an oxygen cutting machine as heavy as necessary to carry all modern control equipment. It is possible to feed information to the electric drive motors of the carriage and cross-arm from any desired source. Adaptations of these machines are arranged to use pilot machines, which have a photocell tracing means and may follow reduced scale drawings. The most recently developed control devices for cross-carriage machines consist of calculated profile programs, placed on either punched or magnetic tapes. These tapes, in turn, control the shape cutting by suitable impulses to the cutting machine drive motors.

MATERIALS HANDLING SYSTEMS

Materials handling facilities are required for efficient operation of both portable and stationary oxygen cutting machines. These generally consist of an overhead crane and a multipoint table to support the work. Some of the more specialized machines can use roller table conveyors. The work-holding table, in any event, should be constructed to hold the work with the least possible interference with the cutting operation and should be designed to permit proper disposition of scrap pieces.

GAS SYSTEM

A gas system must be engineered to supply adequate quantities of oxygen and fuel gas for the maximum number and size of torches to be used. The manifolds, pipe lines, regulators and hoses, as well as the source of gas supply, must all be of sufficient capacity.

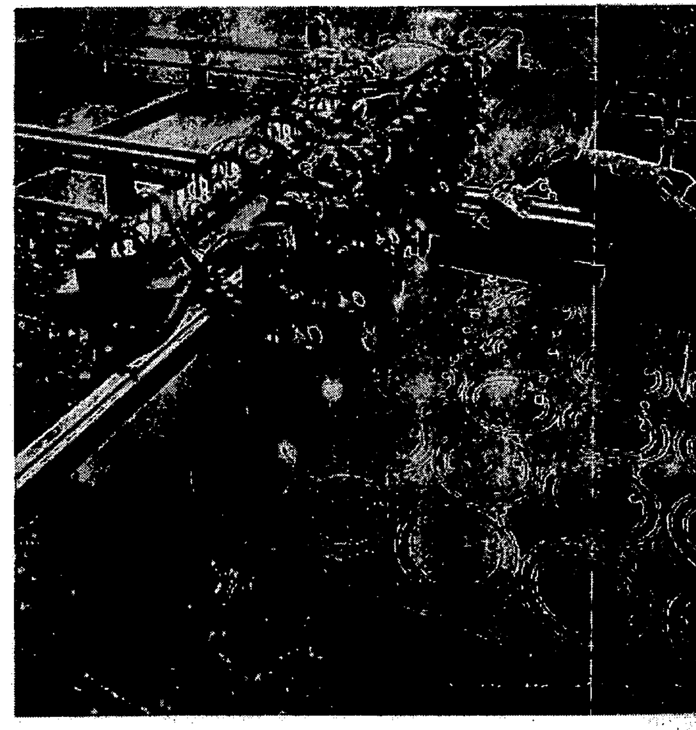


Fig. 42.21.—Multiple torch plate cutting procedure showing five torches in simultaneous operations.

APPLICATIONS

MULTIPLE-PIECE PRODUCTION

In shape cutting, multiple-torch units are frequently used for multiple-piece production and for plate edge preparation where more than one torch at a time is needed to produce the proper edge configuration. In multiple-piece production, it is possible to produce any number of pieces at one time, with additional torches on the same bar being guided around the same shape.

SHIPBUILDING

Ship plate cutting, because of lofting developments, has resulted in the development of very large automatic cutting machines for oxygen cutting several large plates simultaneously. This may be done from reduced 1:10 or 1:100 scale template drawings. Oxygen cutting is also used in many areas other than the plate fabrication shop. These applications include the use of manual oxygen cutting torches to change parts, to remove tack welds and to back-gouge welds.

STEEL MILLS

The adaptability of the oxygen cutting process to steel mill operations has resulted in a number of special applications.

Specially designed oxygen cutting machines for cutting steel billets and blooms in rolling mills have been devised. These are usually heavy, rugged, straight line cutting machines capable of cutting across the bars at rolling mill temperatures, thereby replacing mechanical or hydraulic shears. Blooms and bars up to 60 in. wide or more can be cut by a properly designed oxygen cutting machine. The main advantage of oxygen cutting machines is that they may be of lighter construction than shears and are less apt to break down because they are not subject to shock. In addition, because of their construction, the capital cost and maintenance of oxygen cutting machines is much less than that of shears. The major disadvantage of oxygen cutting machines for such steel mill applications is the relatively slow speed as compared to shears.

There are also heavy-duty machines for cutting heavy buttons that result from steel mill operations and machines for cutting such items as heavy forgings. Other machines are employed to cut finished beam sections to size and to trim off the cropped ends, as well as cutting Tee sections and other special shapes that cannot readily be sheared.

STEEL WAREHOUSE

In the steel warehouse, where it facilitates quick shipment of any desired size and shape of plate to the customer, oxygen cutting has become a vital part of the housing.

CONSTRUCTION

Oxygen cutting is an accepted tool in all the major construction industries using steel as the basic material. The facility with which it can economically cut steel of various thickness and intricate shapes has made oxygen cutting a major process in the production of steel plate shapes.

SCRAPPING AND SALVAGE

Oxygen cutting has proven to be the most economical process for the salvage and scrap industries. Without the use of oxygen cutting to demolish structures, ships and equipment, it would be difficult to dismantle such structures economically. Oxygen cutting permits the ready reduction of steel scrap to suitable size for shipment to steel mills for future steel production. Many salvage operations, especially underwater work, can only be accomplished by oxygen cutting to remove debris and damaged sections, allowing repair work to be undertaken.

EMERGENCY WORK

Oxygen cutting is an essential tool for emergency work. Many police and fire departments, as well as other rescue teams, have oxygen cutting equipment available. The oxygen and fuel gas cylinders are in a self-contained, readily portable unit.

AUXILIARY PROCESSES

Auxiliary processes include scarfing, gouging, grooving, washing, piercing and lancing. The chemistry of these reactions is the same as that described in the preceding section concerning oxygen cutting. Basically, the metal is heated to its ignition temperature and then high-purity oxygen is supplied to cause rapid oxidation and melting of the metal.

SCARFING

Scarfing or deseaming covers those operations involving the surface conditioning of steel blooms, slabs and billets preparatory to finish rolling in the steel mill. It has largely replaced chipping with the pneumatic hammer for the removal of cracks, seams, scabs and crows-feet from steel stock.

Scarfing has decided advantages over chipping as a means of removal of these defects. It is much faster than chipping. It also results in reduced floor space requirements for steel conditioning operations. Scarfing makes it possible to salvage many steel stocks too badly checked to warrant chipping. Contrary to supposition, scarfing does not cover up defects but actually exposes small cracks and imperfections which other methods may not reveal.

Another important application of hot manual scarfing is the removal of tears and scabs resulting from forging and pressing operations, thus eliminating the need for cooling and reheating cycles common to chipping operations.

Manual Scarfing Technique

The technique of scarfing is as follows: A spot on the surface is heated to the ignition temperature. During the preheating, which also loosens the surface scale and exposes clean metal, the tip is held at an angle of approximately 75° to the work, with the tip of the preheating flame almost touching the metal surface. The preheated area should be as extensive as possible to assure rapid starting and to prevent excessive digging at the beginning of the scarf. When the steel under the preheat flames has reached the proper temperature, the nozzle is rapidly drawn backward about an inch and the angle between the torch and work is reduced. The scarfing oxygen orifice is thus positioned so that the oxygen stream will impinge upon the preheated area when the oxygen valve is opened. The operator then depresses the scarfing (cutting) oxygen valve and simultaneously moves the torch forward at uniform constant speed.

Most manual scarfing torches are equipped with a rod feed starting device. Automatic rod starting results in instantaneous starts without the need for prolonged preheat or manipulation of the angle of impingement of the preheat flames on the workpiece. In general, the rod starting devices are arranged

so that, when the scarfing oxygen lever on the torch is initially depressed, approximately 3/8 to 5/8 in. of 3/16 in. diameter steel rod is fed down in front of the preheat flames and the scarfing oxygen orifice. As the scarfing lever is depressed still further, the scarfing oxygen valve is opened, thereby causing the heated portion of the rod to oxidize immediately. The scarfing oxygen stream impinges the burning steel of the rod on the surface of the material to be scarfed. The pattern of the impingement of the oxidizing metal approximates that of the scarfing oxygen stream thus producing a start which has essentially the same width as the remainder of the scarfed path. The oxidization of this small amount of steel rod liberates heat sufficient to permit instantaneous starts to be obtained. Under normal circumstances the scarfing oxygen lever is depressed in one continuous motion, upon completion of which the forward movement of the torch is started.

After the scarfing operation has commenced, the forward motion of the torch should be continued without interruption or hesitation. During forward motion, it is possible to alter the angle of the nozzle to the steel surface or to vary the forward speed in order to control the width and depth of the scarf.

When an entire surface is to be scarfed and a series of adjacent passes are required, the first pass is usually made nearest to the worker. Subsequent passes should then be made on the far side of the previous scarf, allowing sufficient overlap to remove defects. When the tip is angled slightly away from the worker or toward the right of the direction of travel (when travel is from right to left), the slag will be washed to the far side of the scarf. Succeeding passes of the torch will remove the slag remaining from the preceding scarf without leaving excessive fins on the sides of the scarf.

If the tip is held directly in line with the direction of forward motion, a deep, narrow scarf results. The slag removed from the scarf may be blown to both sides, and may form parallel fins on the surface, depending upon the carbon content of the steel. Fins are then removed by other cleaning methods.

After successive passes of the torch a properly scarfed surface is covered by a light, flaky oxide coating that may be removed by a wire brush, leaving a bright clean, finished surface. If any defects remain, they will be clearly visible and can readily be marked for additional treatment. The finish will be superior to that of steel cleaned by chipping.

Mechanical Scarfing

It is posible to mechanize the scarfing process in its simplest form by mounting the scarfing torch on a machine that permits control of the motion between the torch and the workpiece.

In practice, mechanized scarfing is performed with a nozzle that forms a continuous sheetlike stream of oxygen for the scarfing reaction. The scarfing nozzles are mounted on scarfing machines that are designed to fit into the production rolling line. The majority of the scarfing on semifinished materials is done in the production line at rolling temperature, normally 2000°F (1043°C).

Hot scarfing speeds may vary from 50 to 250 linear feet per minute so that steel can be conditioned without interrupting the rolling process. The modern scarfing machines can condition the four surfaces on billets, blooms and slabs over a wide size range. Where entire surfaces are being removed, the surface is usually removed to a depth calculated to result in the elimination of all or the greatest possible proportion of surface defects. For direct rolling to final product size, an initial scarfing depth should be selected to approach 100% surface conditioned yield in the final rolled product. Where the rolling cycle is interrupted, economics may dictate a depth of surface removal designed to result in a minimum amount of manual spot scarfing on the product before reheating for further rolling. Metal loss is a prime consideration when specifying depth of removal, particularly on high-grade steel.

GOUGING

Gouging is used extensively to remove deep defects in steel revealed by scarfing, and by radiographic, magnetic particle, ultrasonic and other inspection methods. Other applications include the removal of tack welds or defective welds, defects in steel casting owing to blowholes or sand inclusions, welds in temporary brackets or supports, flanges from piping and heads and old tubes from boilers. It is also used in demolition work and in the preparation of plate edges for welding.

Manual gouging provides a rapid method of metal removal. Speeds from 1 to 7 linear feet per minute have been obtained. Depending upon the skill of the worker, it is possible to control the accuracy of the gouge to a tolerance of about 1/16 in. in both width and depth. The equipment is readily portable and can be used for the removal of otherwise inaccessible defects. The process is relatively quiet and maintenance costs are less than for mechanical processes that require repeated sharpening of tools.

Gouging Technique

Oxygen gouging is a modified oxy-fuel gas cutting process for producing a fully controlled groove or gouge. Small orifices in the end of the nozzle supply mixed oxygen and fuel gas for the flames to preheat the steel surface to its ignition temperature. The torch should remain stationary until the ignition temperature has been reached. The gouge is slowly started by gradually depressing the cutting-oxygen valve and at the same time retracting the torch a short distance. The nozzle is then turned in a smooth downward arc until the angle between the nozzle and the work is reduced to the correct operating angle. The nozzle is then moved forward along the line of cut.

Progressive Gouging.—A standard manual torch is used in oxygen gouging. The gouging tip is designed to deliver a high volume flow of oxygen at relatively low velocity. The correct tip or nozzle is first selected depending on the size of the desired gouge. The choice may be based upon the experience of the individual or the data provided in Table 42.6. The oxygen pressure is then regulated to give the desired width and depth of groove. The data in Table 42.6 apply for average conditions and for best results tests may be necessary in order to select optimum operating conditions.

Table 42.6—Operating data for gouging equipment

Tip Dia., In.	Oxygen Regulator Pressure, Psi*	Consumption, Cu Ft Per Hr			Approximate Speed, Ft per Min	Approximate Width, In.	Gouge Depth, In.
		Acetylene	Preheat O_2	Gouging (Cutting) O_2			
0.130	65	35–38	35–38	78–82	1.0–1.2	5/16	1/8–3/16
0.130	70	35–38	35–38	88–92	1.4–1.6	5/16	5/32–7/32
0.130	75	35–38	35–38	98–102	1.5–1.8	5/16	3/16–1/4
0.190	80	50–55	50–55	170–175	1.6–1.9	3/8	3/16–1/4
0.190	85	50–55	50–55	188–192	1.8–2.0	7/16	7/32–9/32
0.190	90	50–55	50–55	205–210	1.9–2.2	7/16	1/4–3/8
0.250	90	55–60	55–60	278–282	1.9–3.2	1/2	3/16–1/4
0.250	95	55–60	55–60	308–312	2.3–2.6	5/8	1/4–3/8
0.250	100	55–60	55–60	328–332	2.5–2.8	5/8	5/16–9/16

* Pressure measured at the regulator; acetylene pressure 10 psi in all cases. Tips can also operate on low-pressure acetylene with appropriate torches.

In starting the gouge, the torch is held with the end of the tip or nozzle at an angle of approximately 30 to 45° to the workpiece (Fig. 42.22A), so that the tips of the inner cones of the preheat flames just touch the work. The preheat flames are then directed to the area where the gouge is to be started, until the surface reaches the ignition temperature. The angle between the tip and the surface is then reduced to between 15 and 20° and the tip is immediately withdrawn so that the inner cones of the preheat flames are from 1/4 to 1/2 in. behind the preheated area (Fig. 42.22A). The oxygen control lever is also gradually depressed and the torch is advanced as soon as the reaction starts. The gouge progresses slowly while the angle of the end of the tip is gradually reduced to the final operating position of 5 to 25° (Fig. 42.22B). The proper angle will be readily discernable. If the tip is not lowered far enough some of the slag tends to flow backward into the gouge toward the operator; if it is lowered too far, however, the gouge will become shallow and will soon be lost. Best results are obtained when the torch is held with the tip clear of the bottom of the groove.

About 2 feet per minute is the approximate torch travel speed for making a clean gouge 3/8 in. wide and 1/4 in. deep in cold steel plate.

When it is necessary to change the direction of the gouge, the angle of the nozzle in relation to the work should remain unchanged while the torch is rotated to the new direction. Too sharp a turn should be avoided to prevent the outside wall from being cut into as a result of the molten slag action. It is advisable to use lower oxygen pressures than those indicated in Table 42.6 when not gouging in a straight line.

The depth of the gouge is a function of the speed of progression and the angle between the oxygen stream and the work. To cut a deep gouge, the angle of the torch is increased in relation to the gouge and the speed is correspondingly decreased. To make a shallow gouge, the procedure is reversed. Gouges can be made as deep as they are wide or slightly deeper. Furthermore, successive passes can be made to reach the bottom of a defect that may be as much as 2 to 3 in. below the surface.

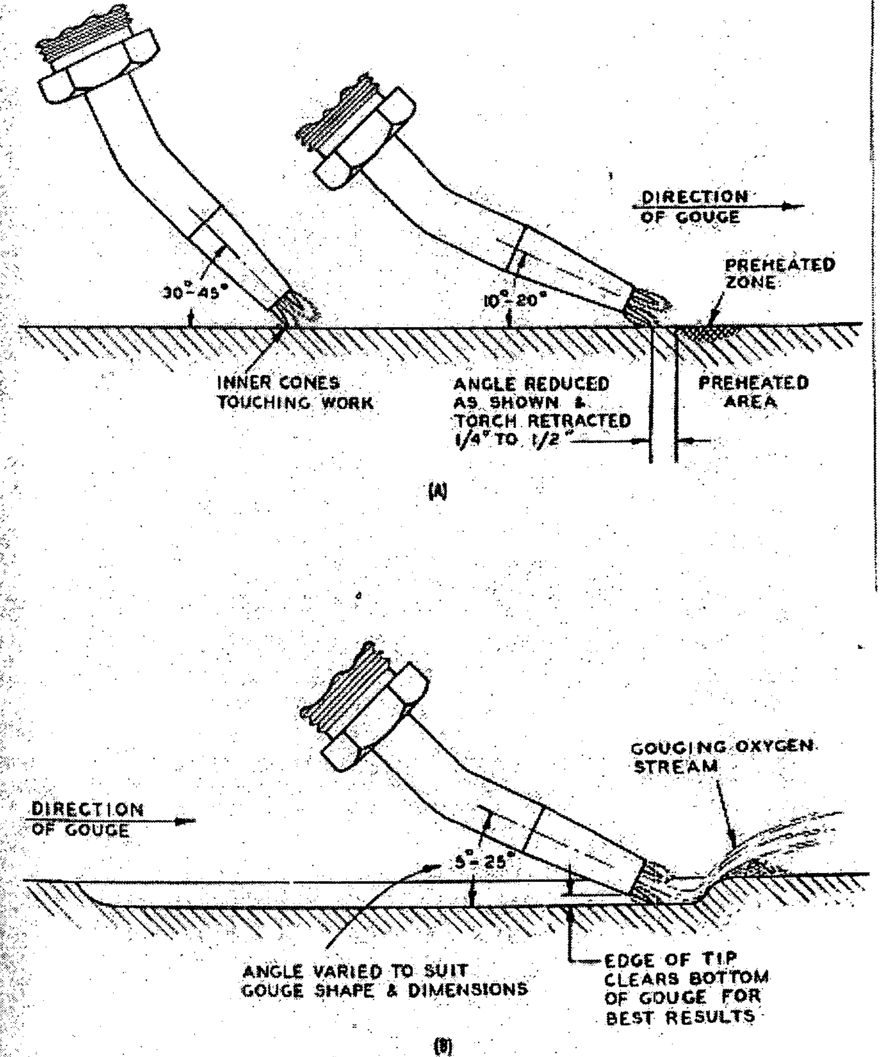


Fig. 42.22.—(A) Schematic showing nozzle angle for preheating (left) and for start of gouging operations (right). (B) Schematic diagram of oxygen cutting torch held at a proper angle for gouging.

The contour of the gouge is dependent upon the characteristics of the tip used and the operating conditions. If the oxygen pressure is too low, the gouging action will be very shallow and slow. Too high an oxygen pressure requires rapid tip movement to prevent a deeper gouge than is desired, and to prevent piercing of the plate.

Gouging operations can be mechanized by mechanically moving the tip relative to the work. Gouges are obtained smoother and more accurate than can be cut with manual operations. Gouging speeds are from two to five times faster than cutting speeds and therefore require machines with higher driving speeds.

Backstep Gouging.—The backstep method was developed to facilitate removal of defective welds and imperfections in the base metal. The nozzle is held in a similar position to that used in the progressive method during preheat. After the starting point has been heated to the ignition temperature, the oxygen valve is opened and the tip is moved to the line of gouge but in a backward instead of a forward direction for 3/4 in. while the angle between the tip and the plate is gradually increased. The oxygen valve is then closed and the torch moved forward along the proposed line of gouge for approximately 1 1/4 inches. A puddle of molten metal can be maintained with the preheat flames to facilitate rapid start of the next gouge. The oxygen valve is again opened and the torch drawn backward until the gouge made by the preceding pass has been reached. This intermittent sequence and the rocking motion produced by inclining the torch is repeated along the entire length of the defective section of the weld.

Spot Gouging.—Single weld defects are removed by spot gouging. The defect is first outlined on the surface of the weld and a starting point a little to the rear of the defect is selected. The exact location depends upon how deep the defect is judged to be. The gouge is then started in the usual manner, but instead of reducing the angle of the tip, it is increased gradually so that the oxygen jet is directed downward until the gouge has penetrated to the depth of the defect. With a little experience any defects can be readily observed as dark streaks through the red color of the reaction zone. The torch should be held so that the tips of the inner cones of the flames are about 1/16 in. above the plate surface at all times during the operation. The resulting gouge is narrow and U-shaped and can be filled with weld metal without difficulty.

GROOVING

Grooving is similar to gouging. A straight nozzle is generally used rather than a bent one and the torch is usually mounted on a tractor-type cutting machine, which produces a more uniform groove. This process is similar to scarfing and gouging except that a deeper, narrower groove can be obtained.

Grooving Technique

Grooving is used to prepare the edges of heavy plate for welding. The objective of this edge preparation is to obtain a contour similar to a "J." When two pieces of plate prepared in this manner are placed together, the resulting groove is in the shape of a "U." J-grooving can be done by three different methods: machine planing; thermal cutting, with which it has been possible to produce J-grooves in plate up to 1 1/2 in. thick in two passes by following a bevel cut with a gouging pass; and by a recently developed J-grooving method. This latter method utilizes an oxy-fuel gas flame applied in a single pass to plates between 1 1/2 in. and 4 in. thick and to plates of greater thickness in a dual pass combination. With single-pass J-grooving, the desired "J" groove contour is produced repeatedly. The nose width and the groove radius are maintained to specified dimensions (Fig. 42.23).

J-grooving may be applied to either horizontal or vertical plate and to curved sections. An adequate installation is required to produce successful and repetitive single pass J-grooves. Proper operating techniques and conditions are also required. Variables that must be controlled include processing speeds, cutting oxygen and preheat gas flows, and nozzle angle and distance settings.

The basic components of a J-grooving installation are a J-grooving nozzle, an adequate gas and oxygen supply, a nozzle positioning device, a plate follower, and a machine tractor to act as a motivating force (Fig. 42.24).

The four variables encountered when positioning "J" grooving nozzles are: (1) the impinging angle (θ) Fig. 42.25A; (2) the lateral angle (ϕ) Fig. 42.25B; (3) the slot angle (ψ) Fig. 42.25C; (4) the slot distance (a) Fig. 42.25C.

Operating conditions and variables for 1 1/2 to 4 in. thick plates shown in Table 42.7 will produce J-grooves with a 3/16 to 1/4 in. nose, a 3/8 to 3/4 in. groove radius and a 5 to 7 1/2° bevel angle. The larger dimensions are for the thicker plates.

At the start of the J-grooving pass, there is a short distance before the groove actually assumes its final depth and contour. Therefore, it is necessary to use a starting tab lightly tack welded to the edge of the plate and long enough to ensure that a full-depth groove is being made before the plate itself is reached. Typical lengths vary between 8 and 12 in.; the shorter tabs for the thinner plates and the longer tabs for the thicker plates.

Using the data presented in Table 42.7 it is possible to estimate J-grooving costs and to predict the subsequent welding requirements. Calculations based on known gas flows, processing speeds and J-groove cross-sectional areas are shown in Table 42.8. Total gas costs can be determined by applying current price schedules to the gas consumptions. As shown in Table 42.8, the weld area is twice the J-groove area and is formed when two J-grooves are placed in welding position to form a U-groove.

Single pass J-grooves are limited to plates having a maximum 4 in. thickness, but thicker plates can be J-grooved by utilizing a two-pass technique in which a standard J-grooving pass is followed by a cutting operation to remove excess metal along the lower edge of the plate as shown in Fig. 42.26.

In J-grooving it is essential that plate edges be perpendicular to the plate faces since the resulting bevel angle is always relative to the face of the plate edge.

J-grooving can also be done on top edges of plates in a vertical position. However, the effect of gravity for slag removal is lost and it becomes necessary to compensate for this loss by employing an air jet to blow away the molten slag.

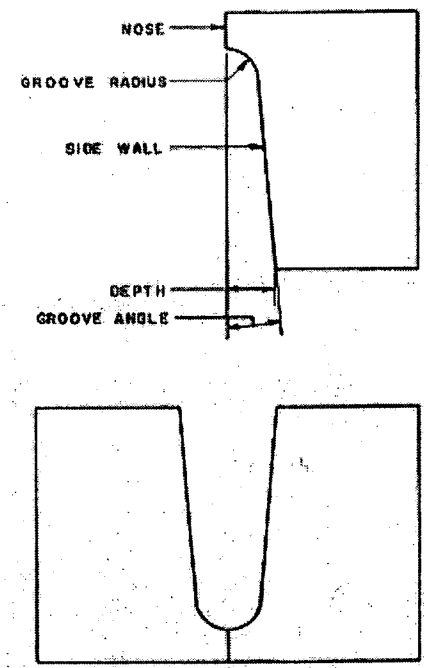


Fig. 42.23.—Characteristics of a single-pass oxy-fuel gas flame cut J-groove.

Single-pass J-grooving can also be applied to the preparation of circular pressure-vessel drum ends and end caps. Standard conditions are maintained except that the nozzle remains in a fixed position while the workpiece is rotated at a circumferential speed equal to the recommended carriage speed.

Heat-affected depths and hardnesses are no greater than are encountered in oxygen cutting. Single-pass J-grooving with an oxy-fuel gas flame can be performed on any steel that can be oxygen cut.

WASHING

The technique used in washing is almost identical to that employed in scarfing and gouging. It is usually applied to castings where risers, pads, gates or fins are cut down and blended with the remainder of the surface.

Pad Washing—In foundries, risers and gates are generally cut off reasonably close to the surface of the finished casting. The cutting may be accomplished by abrasive wheels, saws or by a thermal cutting process. It is generally the intricacy of the shape of the casting or the method used in removing a riser or gate that determines if cutting down to the surface level is possible. Any excess metal remaining on the riser pad may be washed down by successive passes and

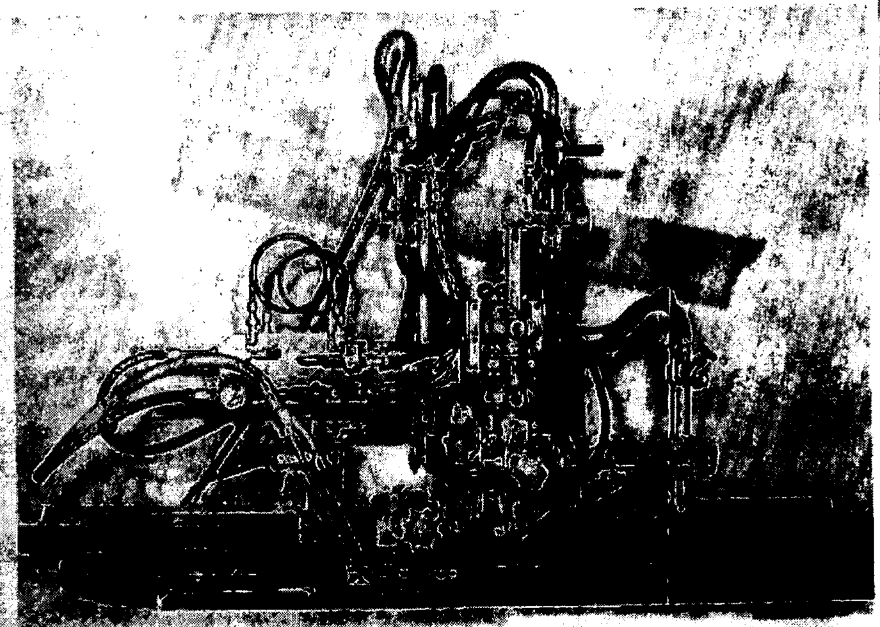
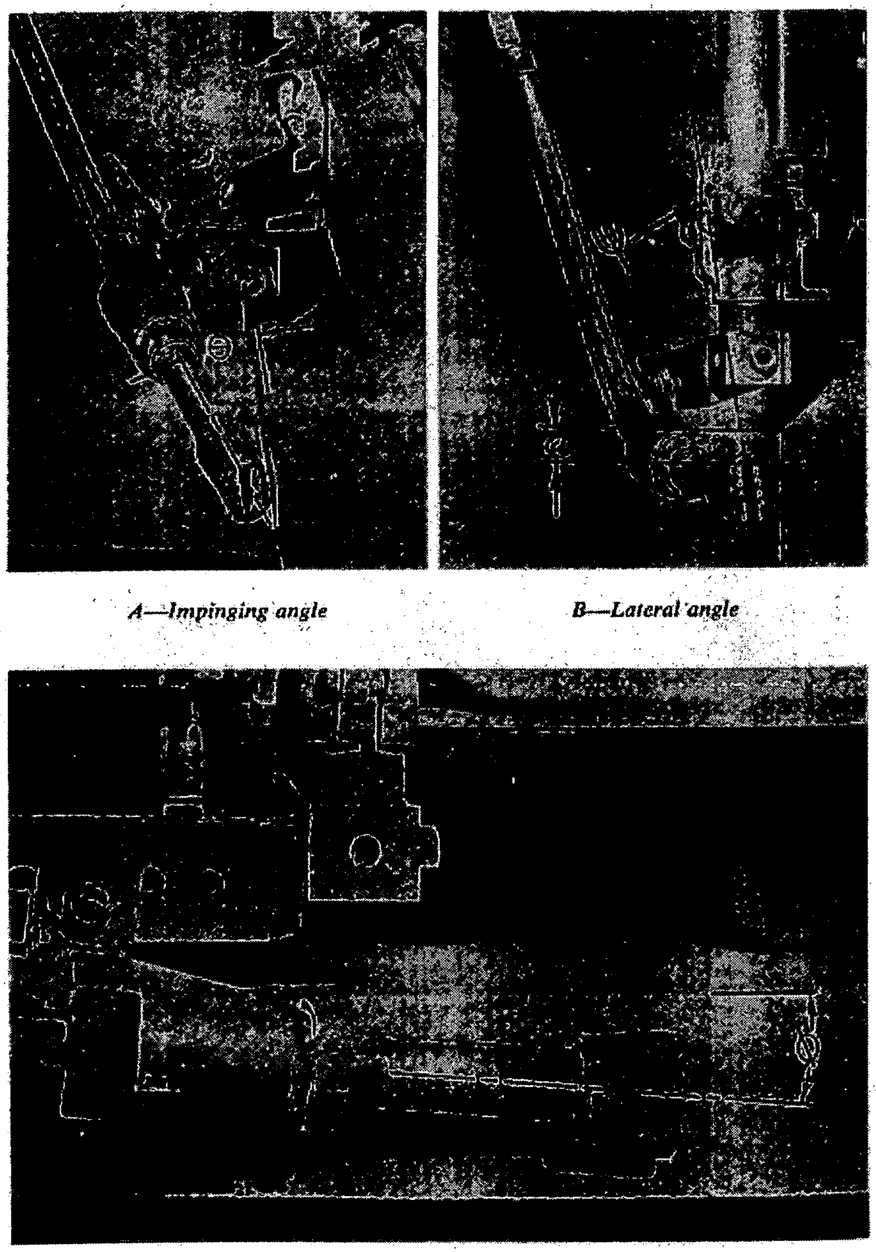


Fig. 42.24.—Single-pass oxy-fuel gas flame J-grooving installation for horizontal plate.

blended in with the cast surfaces. The number of passes required to accomplish this blending is dependent upon the height and contact area of the riser pad or gate above the finished surface desired. On castings of reasonable size, successive washing passes will usually remove approximately 1/8 in. of metal per pass to a width of about 3/4 inches. Passes of greater depth or width are generally not practical because of the danger of cutting into or below the finished surface desired. Grinding of the washed surface is unnecessary when pad washing is skillfully performed.

Fin Washing.—Fin washing is similar to gouging or scarfing, but its purpose is to remove the fins on castings. The fin can usually be washed down to the surface of the casting with a single pass. The technique is essentially the same as that previously described for scarfing, except that a tip with a smaller oxygen orifice can be used at slower speeds. Washing may be accomplished with large bore sizes at speeds higher than those normally used for gouging.

Rivet Washing.—Rivets may be removed by means of the cutting torch. In rivet washing, the rivet is removed by using the cutting torch to consume the rivet head by a washing action. The torch is repeatedly manipulated until the entire rivet head has been oxidized, after which the rivet is punched out. This applies where the rivet has not been deformed. The slag resulting from the washing action is blown away by the force of the cutting stream (Fig. 42.27).



A—Impinging angle

B—Lateral angle

C—Slot angle and slot distance

Fig. 42.25.—Variable encountered when positioning J-grooving nozzles.

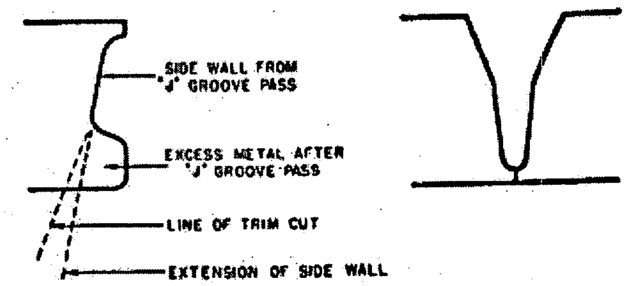


Fig. 42.26.—Two-pass technique of J-grooving followed by oxygen cutting.

The technique can be acquired readily by practice. An experienced person can achieve results wherein the plate remains undamaged and unmarked by the washing action of the oxygen stream. Since the shank of the rivet is merely punched out, the diameter of the hole in the plate remains unchanged. The rivet washing process has wide application when the plates and their existing rivet holes are to be used again.

PIERCING

Piercing is a general term covering operations where holes are to be formed in base material. If the hole is to be finished to a given diameter, the size of the cutting oxygen orifice in the nozzle must be selected with care. The diameter of the preheat circle should also be considered. The oxygen cutting bore in the nozzle is generally held at a right angle to the surface in which the hole is to be pierced. The end of the inner cones of the preheat flames should be positioned just clear of the surface of the material. After the preheated area has been brought up to the oxygen ignition temperature, the cutting oxygen valve lever is depressed slowly. Full oxygen flow through the cutting bore should not occur until the hole has been pierced completely through the plate, or the required depth and diameter have been obtained.

When a hole of large dimensions is being pierced, the tip of the nozzle is held in one position until the required depth is obtained. The nozzle may then be moved in order to obtain the required diameter or shape. It is often advantageous to incline the nozzle at a slight angle and manipulate the torch slightly as the oxygen is turned on. This permits the slag to be blown clear of the tip face.

Rivet Piercing.—In addition to rivet washing, rivets can be entirely removed by piercing. Care should be taken not to damage the holes in the plates through which the rivet passes during cutting out of the shank. This technique is usually performed when the rivet shank cannot be removed by punching because of poor alignment of the original holes in the mating plates. This is a highly skilled operation and great care must be exercised if it is to be successful.

Fig. 42.27.—Typical oxyacetylene rivet washing operation.

Billet Centering—Billet centering is a form of piercing in which a large-size cutting tip is used. It is used extensively in the production of seamless tubing to form a center for the piercing mandrel. The center of the billet end is heated to the ignition temperature and the cutting oxygen is turned on. The size and shape of the hole depend upon the oxygen orifice size, the oxygen pressure, the duration of oxygen flow and the material temperature. Small holes (1 in. deep, with a 1 in. mouth diameter) in hot steel may require only 1 or 2 seconds of preheat time and an application of the cutting oxygen for perhaps half a second. Larger holes (2 or 3 in. deep with a 2 in. mouth diameter) on cold material may require 7 to 10 seconds or slightly more of preheat time plus a 7 to 10 second burst of cutting oxygen. Nozzles and tips used for this work usually have a large number of preheat flames spaced around the oxygen orifice. Portable and stationary billet centering machines are used in production operations. In order to prevent the sparks and slag from blowing back, billet centering may also be carried out with a conventional cutting or scarfiing torch of a greater length than standard torches. Billet centering operations performed on hot steel, or where good control is desired over the depth, diameter and shape of the center require automatic timing devices.

LANCING

Conventional lancing is employed when a very long or deep hole is pierced through a fairly thick metallic body (Fig. 42.28). The conventional consumable lance is a piece of reasonably clean steel pipe from 1/8 to 1 in. in diameter. Oxygen is fed to this lance by means of a hose and the flow is regulated by an oxygen valve. In lancing operations a cutting or welding torch, electric arc or any available means of supplying heat is used to preheat the surface of the material to be lanced. If a cutting torch is used as the preheating medium, the cutting oxygen is turned on in the manner described for piercing. As soon as the pierce begins, however, the oxygen is turned on through the lance pipe, and the end of the lance pipe is brought over the area where the hole is being pierced. As the hole is pierced through the material, some of the steel lance pipe is consumed. A rotary motion is usually imparted to the lance pipe in order to produce a hole larger than the diameter of the lance pipe, thus permitting the slag to be blown out of the hole as the lancing progresses. Some difficulty may be experienced in restarting a deep lance hole once the operation has been stopped. Steel wool padding may be used at the bottom of the hole to reinitiate the reaction. It is always desirable to employ a lance pipe long enough to permit complete piercing of the material in one continuous operation.

AUXILIARY POWDER PROCESSES

The powder process described on pages 42.28-42.31 may also be adapted for scarfing, gouging, washing, lancing, etc. When the powder-laden oxygen stream comes into contact with the preheat flames and the reaction zone, it reacts to cause oxidation, melting and spalling. The circumstances and techniques involved are virtually identical to such conventional operating as oxygen cutting, scarfing and gouging.

Table 42.7—Operating conditions for single-pass oxy-fuel gas J-grooving

Plate Thickness, in.	Cutting Oxygen Flow, cfh	J-Grooving Speed, ipm	Impinging Angle θ, deg	Lateral Angle ϕ, deg	Slot Angle Angle ψ, deg	Slot Distance a, in.
1 1/2	1650	44	15	4	2	7/16
2	1450	24	18	4	4	1/2
2 1/2	4300	40	18	4	4	6/5
3	5000	27	15	2	4	1/2
3 1/2	5000	27	15	2	4	1/2
4	7000	27	18	2	8	1

Table 42.8—Gas consumptions and weld areas for single-pass oxy-fuel gas J-grooving

Plate Thickness, in.	Groove Cross Section Area, sq in.	Total Gas Consumption, cu ft per linear ft of J-groove					
		Oxygen	Acetylene	Oxygen	Propane	Oxygen	Natural Ga[s]
1 1/2	0.375	7.9	0.35	8.2	0.22	7.9	0.27
2	0.650	13.4	1.26	14.0	0.66	13.2	1.00
2 1/2	0.900	22.1	1.28	22.9	0.66	•22.6	1.00
3	1.35	38.6	1.56	40.5	1.13	38.9	2.13
3 1/2	1.65	38.6	1.56	40.5	1.13	38.9	2.13
4	2.20	53.5	1.50	55.3	1.13	54.7	2.13

* Weld area—2 X groove area.

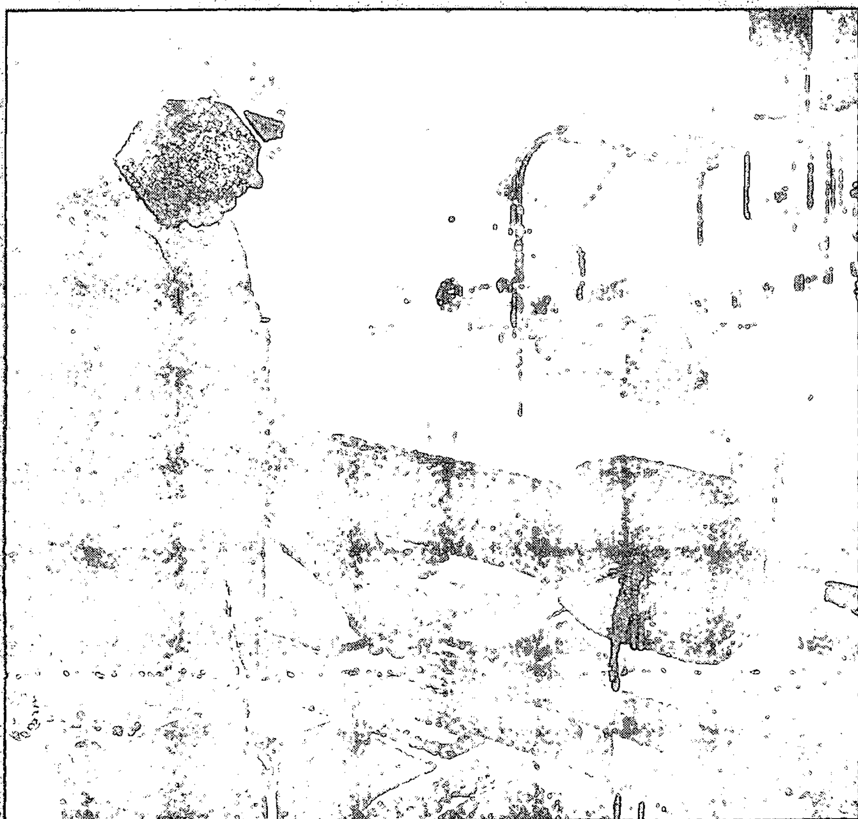


Fig. 42.28.—Lancing a starting hole in the main rod of a locomotive drawbar forging.

Powder Scarfing.—A conventional scarfing torch and nozzle with an external tip may be employed in powder scarfing operations or the torch and nozzle may be designed so that the powder is introduced into the cutting oxygen jet inside the scarfing nozzle.

The opening of the powder valve should precede the opening of the scarfing oxygen valve. Since the starting is instantaneous, no starting rod is necessary, nor is there a need for preheat dwell time. The powder scarfing technique is identical to the technique used for the scarfing of plain carbon steels, except that the distance between the end of the nozzle and the reaction zone must be greater than that ordinarily employed for carbon steel scarfing. Thus, sufficient time is allowed for the powder to be preheated and burned as it impinges upon the surface of the material to be scarfed. Scarfing speeds on cold stainless steel, for example, are generally about one half the speed required for carbon steel. Oxygen consumption is therefore higher, and the width of the scarf is usually about two thirds that obtained on carbon steel (Fig. 42.29).

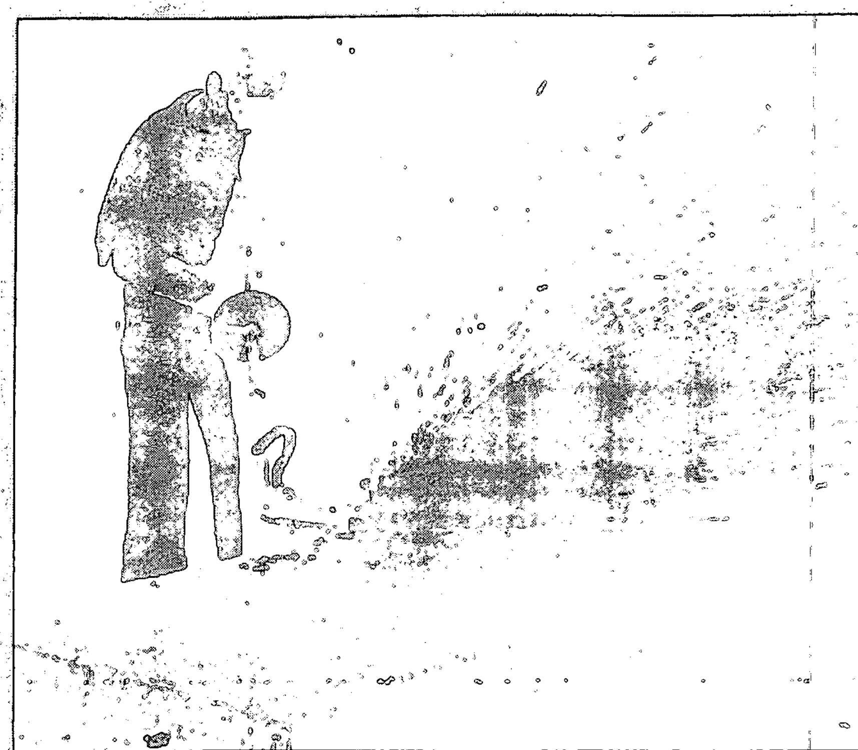


Fig. 42.29.—Stainless steel billet being scarfed with a manual powder scarfing torch.

Powder Gouging and Washing.—Powder can also be introduced by means of an external feed for pad or fin washing or gouging of materials such as cast iron and stainless steel (Fig. 42.30). Powder washing is particularly valuable in the preparation and reworking of carbon steel castings where washouts in the mold have occurred and the resultant areas are laden with molding sand These castings would be difficult, if not impossible, to recondition or reclaim with oxygen cutting or any other conventional cutting means. This washing or gouging is carried out in essentially the same manner as in the conventional process, except that slightly reduced speeds of operation can be expected.

Powder Lancing.—Materials such as concrete, cast or pig iron, and ladle spills resist lancing by ordinary means. They can be lanced, however, by mixing the oxygen with iron powder or mixtures of iron with aluminum or other metallic powders. The powder lancing technique is identical to conventional lancing, except that deeper holes can be cut at much faster speeds. Materials that are highly resistant to other cutting methods can be lanced by means of this technique, and with less consumption of the steel lance pipe. If the end of the lance pipe is heated to the ignition temperature before the mixture of oxygen and powder is turned on, it is possible to restart a lance hole at any time.

Fig. 42.30.—Powder washing technique as applied to casting pads.

EFFECTS OF AUXILIARY OXYGEN PROCESSES ON MATERIAL

Chemical

The chemical effects produced by the auxiliary oxygen processes are similar to those resulting from oxygen cutting when equivalent operations are performed. For a discussion of these effects, reference should be made to the section on effects earlier in this chapter.

The chemical effects, in general, are slight and hardly noticeable and do not interfere with subsequent operations such as welding. When billets and slabs are scarfed in a steel mill, reheating for rolling purposes produces more pronounced oxidation and scaling of the scarfed surface than the surface chemical effects produced by the scarfing process itself.

Metallurgical

The effect of oxygen cutting on the metallurgy of steel is discussed earlier in this chapter. The same considerations apply to the auxiliary oxygen processes. The metal being removed is elevated to a temperature approaching its melting point; consequently, heat is transferred to the steel immediately adja-

cent to the melting zone which is thus heated above its critical temperature. However, most of the auxiliary cutting processes produce a larger area of metal removal than that of oxygen cutting and a greater heat-affected area is produced. The mass of metal at a distance from the operation may not be affected appreciably. These conditions represent typical hardening conditions for the metal in the vicinity of the melting zone with a large temperature gradient from the melting zone to the cooler mass of metal. Stresses of varying degrees are introduced into the part because of this hardening effect and the expansion and contraction of the metal.

Proper precautions are necessary to prevent checking and cracking of the steel surfaces, especially when large billets or castings are being scarfed.

To determine whether special precautions are needed to prevent checking and cracking, the analysis of the steel should be known. Knowledge of the analysis makes it possible to predict the likelihood of checking and cracking by determining the hardenability of the steel. The considerations discussed earlier in this chapter are equally valid for the auxiliary oxygen processes.

The conventional auxiliary oxygen processes (without powder) may be employed on almost all types of carbon and alloy steel. The corrosion-resistant and austenitic stainless steels, cast iron, nonferrous and refractory materials require the use of the powder processes. High carbon and alloy steels must be preheated sufficiently to reduce cooling stresses and also to minimize the percentage of martensitic transformation in the affected area. Preheating is essential when alloys containing nickel or chromium are processed. Where billets are scarfed in steel mills during rolling operations, scarfing is often performed by machine in the roll line at rolling temperatures usually between 1800 and 2000°F (982 and 1093°C). When scarfing is not performed during the rolling cycle, preheating temperatures from 400 to 900°F (204 to 482°C) have been found adequate for many steels. Many steels may be scarfed cold without danger of cooling cracks. In practice, however, it is preferable to determine the required preheating temperature by experience with the particular type of steel being used.

Some borderline steels require preheating in winter but not in summer. Regardless of the nature of the alloy, a preheat of the material decidedly improves the operational ability of any of the auxiliary oxygen cutting processes.

STEEL ALLOYING ELEMENTS

The auxiliary oxygen cutting processes may be used on all grades of steel with the exception of those steels whose chemical analysis would tend to result in fissuring and cracking.

Corrosion-resistant and heat-resistant steel alloys usually contain nickel, copper, cobalt, chromium or aluminum. Such alloys are not readily shaped by the auxiliary oxygen processes unless a chemical flux or iron enriched powder is introduced into the oxygen stream. These compounds either remove the refractory slag or aid in the melting of the slag.

High-carbon steels can be scarfed without difficulty if they are preheated. Steels with carbon contents as high as 1.36% have been scarfed successfully. Scarfing of high-carbon steels containing nickel or chromium up to 3% is a standard commercial practice. Manganese as an alloying element is not detrimental. Steels with a manganese content as high as 10.5% are processed easily.

High-manganese steel with high sulfur content does not prove troublesome. Silicon in the amount usually found in steel does not appear to be detrimental.

QUALITY OF SURFACES

The desired contour of the surface depends to a large degree on the purpose for which the material is intended. Surfaces that have been gouged for the removal of defects prior to rewelding require a smooth, fairly accurate groove. It is necessary to gouge out the defect with a minimum removal of adjacent sound metal. A narrow, deep groove is usually the ultimate aim. Other work such as pad washing, fin washing and scarfing requires the removal of metal in wide, shallow passes. Ridges or fins may be formed between the various passes. If such ridges are present, they should be of minimum height. The shaping of a large shaft to fit a wobbler plate in the drive mechanism of a steel mill roll assembly, or a J-groove in the edge of a plate are examples indicating the variety of end results obtainable with the auxiliary oxygen processes.

By proper selection of equipment and technique, all contour requirements can be obtained. Different types of contours used in the various auxiliary operations are sketched in Fig. 42.31. Typical gouging operations on arc welds are depicted in Fig. 42.32. The dotted lines show the metal removed by gouging. It should be noted that the U-grooves shown in Fig 42.32A and C are produced by oxygen gouging, as is the Vee-groove with a rounded bottom (Fig. 42.32B). A wide range of widths and a variety of shapes of grooves can be produced by a skilled worker using suitable apparatus.

EQUIPMENT USED

Manual Scarfing, Gouging and Washing

A scarfing torch (Fig. 42.33) differs from a conventional cutting torch in four principal respects:

1. The torch is usually 36 to 72 in. long. The operator is permitted to work in an almost erect position, permitting easy handling of work at floor level.
2. The oxygen flow requirements for scarfing may greatly exceed those of normal cutting.
3. Most scarfing nozzles are larger in diameter and size of oxygen bore than the normal cutting nozzle.
4. Most scarfing torches are equipped with a rod feed device for obtaining faster starts. Torch head angles usually range from 65 to 90 degrees.

The amount of preheat required is usually equal to that needed for cutting with a very large cutting tip. Where no rod feed is used and relatively rapid preheating is required, it is invariably necessary to increase the preheat capacity of the nozzle. A tip suitable for surface removal by means of manual scarfing

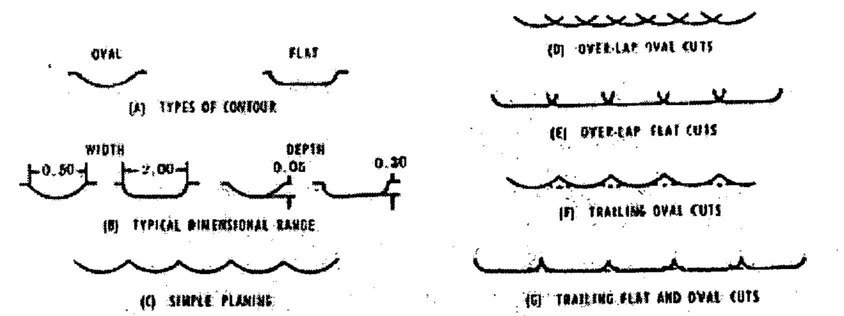


Fig. 42.31.—Typical surface configurations possible with the auxiliary oxygen cutting processes.

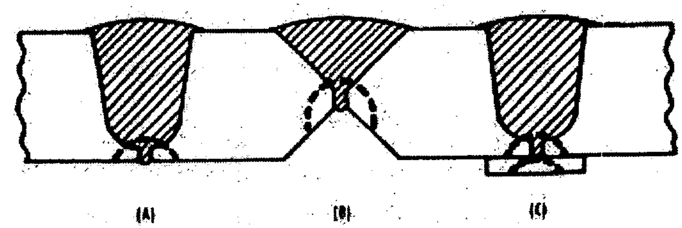


Fig. 42.32.—Typical gouging operations that may be applied to arc welds.

is desired; it is customary to use a nozzle with a very large outlet bore, thereby producing a scarf on each pass 20 to 50 times as wide as it is deep. A slotted nozzle orifice must be oriented with respect to the surface being removed. For this reason most manual scarfing is done with a round bore.

Gouging or grooving is usually performed with a conventional manual cutting torch. The head angle ranges from zero to 90° depending upon the application.

Pad, fin and rivet washing are performed be means of conventional cutting torches. A convenient head angle, providing the best control over the process, is employed. The torch length, preheat and oxygen capacity are the same as are required for manual cutting.

The most important consideration in the use of manual scarfing, gouging and washing is the selection of an appropriate tip for a particular application. For surface scarfing operations the tip is designed to remove metal from a wide area, but a shallow depth. Other tips are available for making a narrow groove, and can produce a cut of considerable depth when the correct technique is used. Such a tip would be used to remove deeply located defects in welds. Porosity in castings can be removed similarly, and the minimum amount of metal is removed in order to reduce the amount of welding necessary to correct the defect. Tips for various fuel gases are available.

Conventional cutting torches with convenient head angles are used for piercing. The nozzles used are generally standard cutting nozzles. The size of the orifice chosen depends on the skill of the individual operator and the depth of the hole.

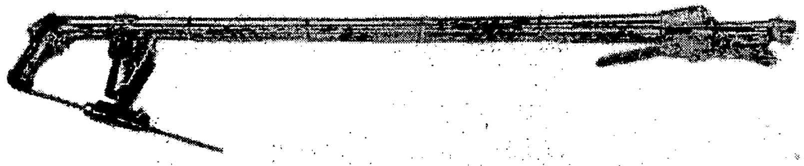


Fig. 42.33.—Typical manual scarfing torch.

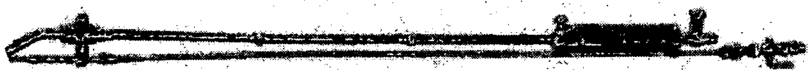


Fig. 42.34.—Washing torch with an iron powder nozzle.

Billet centering may require the use of a torch that is longer than the conventional cutting torch, in order to prevent the slag and sparks from being blown back.

Oxygen lancing can be carried out by either screwing a piece of steel pipe into a suitable adaptor for the oxygen supply bore or by means of a collecting and sealing device for the lance which eliminates the need for pipe with a threaded end.

The torches used for powder cutting are usually specially designed for the purpose (Fig. 42.34). The powder valve may be a separate part of the torch or it may be integrated with the cutting-oxygen valve. In the latter case, by depressing the cutting valve lever, the powder and oxygen are opened in a preselected sequence. The conduit carrying the powder from the powder valve to the torch head or to the powder attachment may be built into the torch. Torches are available with various nozzle head angles. Powder cutting attachments are also available for use on standard cutting torches, necessitating separate operation of the cutting-oxygen valve and the powder valve. The powder tube is usually attached to the outside of the torch handle. This arrangement permits the use of a conventional torch for powder cutting or scarfing.

A recently developed powder lance utilizes a collecting and sealing device integral with a handle upon which are located separately operable but interlocked oxygen and powder valves. Unthreaded pipe can be used. The powder and oxygen enter the lance pipe close to the handle.

In general, most of the equipment used in these processes is identical to that employed in cutting operations. Regulators, hoses, valves, fitting, etc., should be of sufficient capacity to handle the gas flows required for the particular process. Obstructions in gas supply systems should be avoided and nozzles designed for specific fuel gases should be used.

Mechanical Scarfing and Grooving

Fixed-position scarfing machines mounted directly in the roll line of the steel mill are used today mainly for scarfing blooms and billets with cross sections of 4 to 14 in. on a side, slabs up to 84 in. wide and 18 in. thick, and rounds of commonly rolled sizes (Fig. 42.35).

Surface removal on slabs 76 in. wide to a depth of 1/16 in. on all four sides is possible at speeds of approximately 100 feet per minute with modern equipment. Shallower removal may be acomplished at even higher speeds. These machines perform the same function as manual scarfing torches, but on a larger scale and in an automated manner.

The stationary type scarfing machines are built so that they can be retracted or lifted from the roll line. This permits repairs and maintenance without interrupting the schedule of the mill.

The scarfing units are mounted singly or in groups on one, two or four moveable carrier plates which allow them to be moved into position on the steel. They are adjusted by electric, hydraulic or pneumatic controls for steel sections of various sizes. The units are free-floating and follow the axis of the bloom or slab. The water-cooled scarfing units consist of individual nozzles, block-type tips or slotted segments. The gases fed to the nozzles or segments are controlled either by individual shut-off valves or by large-bore selector-valve manifolds. The entire machine is operated by controls located in the pulpit near the rolling line in a position that provides good visibility for the operators.

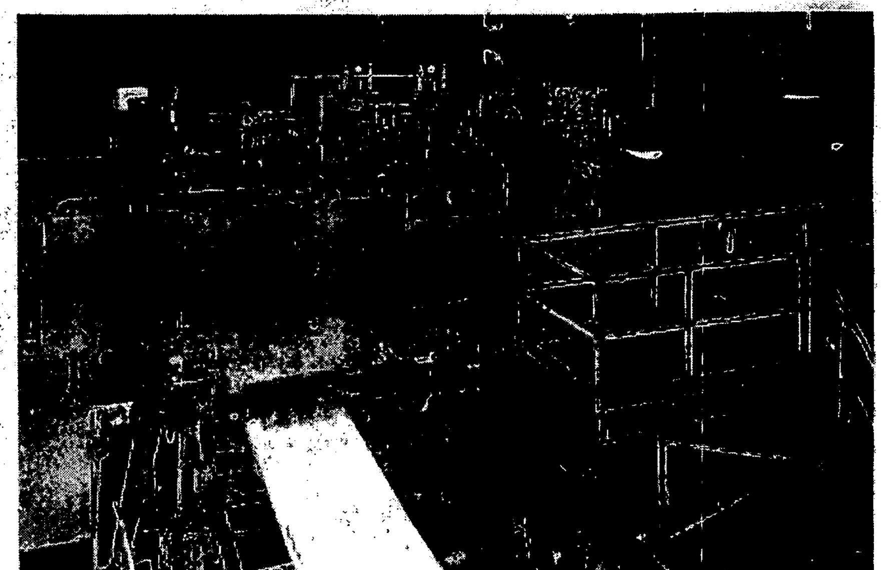


Fig. 42.35.—Machine scarfing of steel slabs in a typical steel mill application.

Another consideration is the provision of adequate facilities for handling the large volume of slag and fumes produced during the scarfing process. Special slag targets equipped with water sprays to break up the slag and flush it away to a settling pit are provided. Fume hoods and exhaust fans are connected to a conveniently located stack. Many of the more modern scarfing machine installations include means for collecting the smoke solids from the exhaust fumes.

The oxygen consumption in mechanical scarfing is among the highest in steel mill work. For an installation capable of handling 200 tons of steel per hour, some 6 tons of surface may be removed. About 7 tons of fumes and slag result, and approximately 20,000 to 25,000 cu ft of oxygen and about 1000 cu ft of fuel gas are required. Short-duty cycles for these machines result in momentary oxygen demands that may exceed 500,000 cu ft per hour. The oxygen supply and gas-handling equipment should be engineered to supply these demands.

The oxygen consumption in terms of the weight of metal removed depends upon a number of factors. These include the speed of scarfing, depth of scarf, carbon content, analysis of the steel and temperature of the steel. An approximate figure for oxygen consumption in cold scarfing ranges from 2 to 6 cu ft per pound of metal removed. For hot scarfing in the vicinity of 2000°F (1093°C), this index is approximately 1.5 to 2 cu ft of oxygen per pound of metal removed. In cold scarfing a large percentage of the metal removed is oxidized, whereas in hot scarfing the resultant slag has an exceptionally high iron content. This slag has been found to contain as much as 45% free iron, indicating that melting is an important phase of the action. This accounts, in part, for the fact that alloy steels may often be scarfed hot, whereas at ordinary temperatures they cannot be scarfed satisfactorily.

Stainless steel billets, blooms and slabs may also be scarfed mechanically with essentially the same equipment used for scarfing carbon steel. Iron powder is dispensed and distributed pneumatically through special equipment and is introduced into the scarfing reaction in a manner similar to that employed in manual scarfing. Mechanized stainless steel scarfing is usually performed on cold steel. Surface removal can be varied from depth of less than 1/16 to over ¼ inch. The speed of scarfing varies up to approximately 40 feet per minute.

Industrial Applications

The steel industries are major users of the auxiliary oxygen processes. Since their introduction, the processes, particularly the scarfing process, have been used extensively to replace grinding and chipping. Because of more stringent buyer specifications regarding surface finish, mechanical scarfing of large tonnages is being performed today. In the future, an even greater percentage of total steel tonnage produced will be scarfed.

The heavy machine tool industries, foundries, shipyards and railroads also use these processes for plate edge preparation and the removal of defects in weldments and castings. These industries use gouging for the correction of spot defects, and they use the cutting torch for rivet washing and removal of damaged riveted steel plates.

Fabrication shops use the auxiliary processes for making initial cuts on large plates and rolled sections. Depending on the surface requirements, the cut produced by these processes may or may not be satisfactory for use as produced. Their uses, particularly the powder processes, have yet to be explored fully.

Salvage industries use the manual gouging and rivet washing processes. Among other principal users of the auxiliary oxygen processes are foundries, where the processes are being used for the removal of riser pads, thus eliminating costly grinding operations.

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